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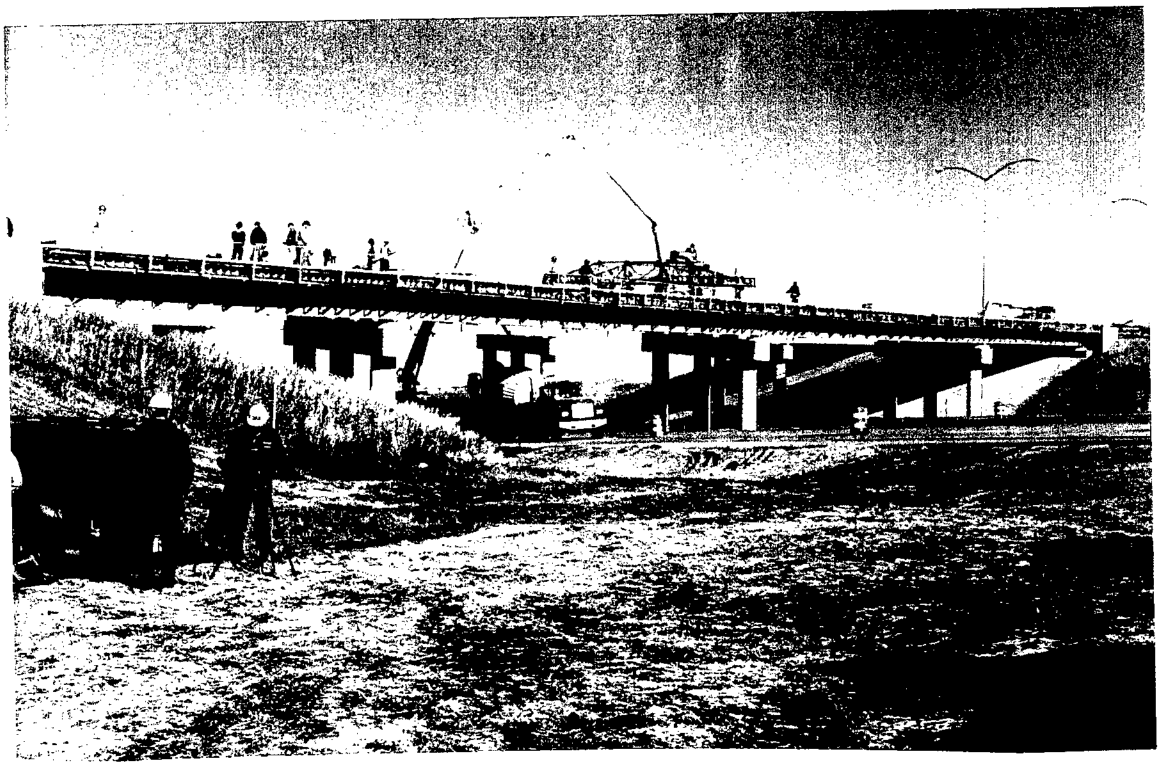

DEMONSTRATION OF POLYOLEFIN FIBER REINFORCED CONCRETE IN A BRIDGE DECK REPLACEMENT

Study SD95-22
Final Report

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DISCLAIMER

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16. Abstract

This report presents the construction and performance evaluation of a full depth bridge deck, and jersey barrier constructed with a new type, non-metallic fiber reinforced concrete (NMFRC).

The mixture proportions used, the quality control tests conducted for the evaluation of the fresh and hardened concrete properties, the procedure used for mixing, transporting, placing, consolidating, finishing, tining and curing of the concrete are described. Periodic inspection of the bridge deck and jersey barrier was done and this report includes the results of these inspections.

The feasibility of using this NMFRC in the construction of highway structures has been established. The new NMFRC with enhanced fatigue, impact resistance, modulus of rupture, ductility and toughness properties is suitable for the construction of a bridge deck and jersey barrier.

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Executive Summary

The constructed facilities of the world have been deteriorating due to the effect of the natural environment, excessive use beyond the original design, aging of the materials and general obsolescence. Fiber reinforced concretes (FRC) are almost ideal materials for repair, rehabilitation, retrofit and renovation of the world's deteriorating infrastructure. The recently developed polyolefin non-metallic fiber reinforced concrete (NMFRC) is one material that promises to provide many advantages, providing a practical approach to enhanced durability and cost-effectiveness in concrete construction. Polyolefin fibers, as compared to steel fiber eliminate problems such as staining, inherent corrosion and potentially harmful protrusions. It has been shown in earlier research and publications that FRC, with its enhanced properties beneficial to structural applications, is a highly suitable material for construction and/or rebuilding bridges and other transportation structures.

The objective of this project was to accelerate the application of polyolefin fiber reinforced concrete through design, construction, evaluation and documentation of a North Bound bridge deck replacement project. The project involved the complete deck replacement of a 102m by 12m (330' by 40') curved steel girder structure carrying US 85 over Interstate 90 near Spearfish, South Dakota. The entire deck and concrete barrier were placed using concrete reinforced with polyolefin fiber.

The ACI Committee 224 report on cracking has recommended that the maximum crack width that can be tolerated under the environmental conditions at the bridge (exposed surface subjected to deicing chemicals) is 0.18 mm (0.007 inches). Therefore the performance of the bridge will be determined by comparing visible cracks and their respective widths to ACI Committee 224's recommended maximum tolerable crack width for preventing the intrusion of deicing chemicals.

The research activities involved were the development of mixture proportions, quality control testing, and advice on the construction, monitoring and evaluation of the structure by periodic condition survey. The test program on fresh concrete included: slump, concrete temperature, fiber content, air content, vebe time, and unit weight. The hardened concrete properties included: compressive strength, static modulus, modulus of rupture, load-deflection curves, first crack toughness, strength and post crack behavior, ASTM toughness indices, Japanese toughness index, equivalent flexural strength, and impact strength. The mixture proportions used, the procedure used for mixing, transporting, placing, consolidating, finishing, tining and curing are described.

The polyolefin fibers were incorporated in the concrete at a rate of 14.8 Kg/cu.m.(25 lbs/cu.yd.). No balling, clogging or segregation was observed during the mixing and placing operations. However, because of a higher slump concrete in two truck loads, there were some bundles that did not open causing the fibers not to disperse. The problem was corrected by increasing the mixing time for loads with higher slump. The same construction techniques and construction equipment without any modification were used in the construction. No difficulty was faced in transporting, placing or tining the concrete, and the workability was satisfactory. The fresh concrete properties of the concrete tested during construction were satisfactory. The air content was slightly less during the bridge deck slab construction, particularly on the first half of the construction, but the air content for the barrier construction was as desired. The slump was measured and averaged of 76mm (3 inches). The mean 28 day compressive strength was 36.96 Mpa (5357 psi), which is above the minimum required compressive strength as specified by the DOT, 31.05 Mpa (4500 psi). There was significant enhancement in the impact strength, toughness, post crack load carrying capacity and flexural strength. The toughness indices showed an increase in elasto-plastic behavior of the concrete in comparison to the plain concrete. Periodic inspection of the newly constructed bridge deck and barrier were made.

The unit cost of the concrete approximately doubled due to the addition of fibers. The only additional cost involved in the mixing, placing, and finishing operations was the expense for adding the fibers to the concrete at ready-mix plant. This additional cost was justified due to the achieved reduction in crack widths, in the deck slab and barriers and thus enhancing the durability of the structure. A visual comparison of this bridge and the nearby companion bridge constructed a year earlier with plain concrete had shown that there was reduction in the number of visual transverse and longitudinal cracks in the bridge deck. Actual counting of the number of cracks and measuring the lengths and widths of the cracks was not done. Looking through the binoculars, it seemed that the crack widths were less in the bridge compared to those of the companion plain concrete bridge.

The post construction performance of the deck slab and barrier was satisfactory and as anticipated. It was observed that the polyolefin fibers helped to contain the crack propagation. Many cracks were observed but mostly of negligible widths. Hence the pattern of a larger number of cracks with smaller harmless widths was observed and this was an anticipated desirable behavior. A visual comparison of this bridge and the nearby bridge constructed a year earlier with non-fiber reinforced concrete had shown that there was a significant reduction in the number and width of transverse and longitudinal cracks in the bridge deck slab.

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GLOSSARY

The following is a glossary of terms for fiber reinforced concrete (FRC) used in this report.

0.1 General Terms

Aspect Ratio - The ratio of length to diameter of the fiber. Diameter may be equivalent diameter.

Balling - When fibers entangle into large clumps or balls in a concrete mixture.

Collated - Fiber bundled together either by cross-linking or by chemical or mechanical means.

Equivalent Diameter - Diameter of a circle with an area equal to the cross-sectional area of the fiber.

Fiber content - The weight of fibers in a unit volume of concrete.

Fibrillated - A fiber with branching fibrils.

First Crack - The point on the flexural load-deflection or tensile load-extension curve at which the form of the curve first becomes nonlinear.

Hairline Crack – Cracks with widths less than 0.1 mm (0.0039 inches) are termed as hairline cracks.

First Crack Deflection - The deflection value on the load deflection curve at the first crack.

First Crack Strength - The stress obtained when the load corresponding to first crack is inserted in the formula for modulus of rupture given in ASTM Test Method C 78.

First Crack Toughness - The energy equivalent to the area of the load deflection curve up to the first crack.

Flexural Toughness - The area under the flexural load-deflection curve obtained from a static test of a specimen up to a specified deflection. It is an indication of the energy absorption capability of a material.

Toughness Indices - The numbers obtained by dividing the area under the load-deflection curve up to a specified deflection by the area under the load-deflection curve up to "First Crack" as given in ASTM C 1018.

Toughness Index, I_5 - The number obtained by dividing the area up to 3.0 times the first crack deflection by the area up to the first crack of the load deflection curve, as given in ASTM C 1018.

Toughness Index, I_{10} - The number obtained by dividing the area up to 5.5 times the first crack deflection by the area up to the first crack of the load deflection curve, as given in ASTM C 1018

Toughness Index, I_{20} - The number obtained by dividing the area up to 10.5 times the first crack deflection by the area up to the first crack of the load deflection curve, as given in ASTM C 1018

Residual Strength Factor $R_{5,10}$ - The number obtained by calculating the value of $20(I_{10}-I_5)$, as given in ASTM C 1018.

Residual Strength Factor $R_{10,20}$ - The number obtained by calculating the value of $10(I_{20}-I_{10})$, as given in ASTM C 1018.

Flexural Toughness Factor (JCI) - The energy required to deflect the fiber reinforced concrete beam to a mid point deflection of 1/150 of its span.

Equivalent Flexural Strength (JCI) - It is defined by

$$F_c = T_b \text{ x } s/\delta_{tb} \text{ x } b \text{ x } d^2$$

where

F_c = equivalent flexural strength, psi

T_b = flexural toughness, inch-lb

s = span, inches

δ_{tb} = deflection of 1/150 of the span, inches

b = breadth at the failed cross-section, inches

d = depth at the failed cross-section, inches

Impact Strength - The total energy required to break a standard test specimen of a specified size under specified impact conditions, as given by ACI Committee 544.

Monofilament - Single filament fiber.
Static Modulus - The value of Young's modulus of elasticity obtained from measuring stress-strain relationships derived from other than dynamic loading.

High Performance Concrete - In this report, High Performance Concrete is defined as a concrete with highly enhanced (or improved) desirable properties for the specific purpose and function for which it is used. It need not necessarily be high-strength concrete. High performance concrete may have one or more of the following properties enhanced: ductility, fatigue strength, durability, impact resistance, toughness, impermeability and wear resistance.

Whitetopping - Whitetopping is concrete placed over asphalt where the concrete thickness is 101 (4 inch) or more mm thick.

Ultra-Thin Whitetopping - Ultra-Thin Whitetopping is concrete placed over asphalt where the concrete is less than 101 mm (4 inch) thick.

0.2 Acronyms Used

ACI - American Concrete Institute

CFP - Collated Fibrillated Polypropylene

FRC - Fiber Reinforced Concrete

LS - Low Slump

NMFRC - Non-Metallic Fiber Reinforced Concrete. This acronym refers only to Polyolefin Fiber Reinforced Concrete. These fibers were manufactured and purchased from 3M for the purpose of this study.

NMFRS - Non-Metallic Fiber Reinforced Shotcrete

PFRC - Polypropylene Fiber Reinforced Concrete

PCC - Portland Cement Concrete

SFRC - Steel Fiber Reinforced Concrete.

SNFRC - Synthetic Fiber Reinforced Concrete

SIFCON - Slurry Infiltrated Fiber Concrete

SIMCON - Slurry Infiltrated Mat Concrete

0.3 ASTM Specifications

A 820 - Specification for Steel Fibers for Fiber Reinforced Concrete

C 31 - Practices for Making and Curing Concrete Test Specimens in the Field

C 39 - Test Method for Compressive Strength of Cylindrical Concrete Specimens

C 78 - Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-point Loading)

C 94 - Specification for Ready-Mixed Concrete

C138 - Test for Unit Weight, Yield and Air Content (gravimetric) of concrete

C 143 - Test Method for Slump of Portland Cement Concrete

C 172 - Method of Sampling Freshly Mixed Concrete

C 173 - Test Method of Air Content of Freshly Mixed Concrete by the Volumetric Method

C 231 - Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method

C 469 - Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression

C 995 - Test Method for Time of Flow of Fiber Reinforced Concrete Through Inverted Slump cone

C1018 - Test Method for Flexural Toughness and First Crack Strength of Fiber - Reinforced Concrete (Using beam with Third-point Loading)

C 1116 - Specification for Fiber Reinforced Concrete and Shotcrete

0.4 International Standards

A - American Concrete Institute Committee 544 Fiber Reinforced Concrete

ACI 544.2R.89 Flexural Fatigue Endurance

Impact Resistance

Toughness

B - British Standards Institute

BS1881: Part 2, Methods of Testing Concrete-Vebe Test

C - Japanese Society of Civil Engineers

JSCE Standard III-1, Specification of Steel Fibers for Concrete, Concrete Library, No. 50, March 1983.

- JSCE-SF4 Standard for Flexural Strength and Flexural Toughness, "Method of Tests for Steel Fiber Reinforced Concrete," *Concrete Library of JSCE,* No. 3, June 1984, Japan Concrete Institute (JCI), pp. 58-66.

- "Standard Test Method for Flexural Strength and Flexural Toughness of Fiber Reinforced Concrete, (Standard SF4),"*JCI Standards for Test Methods of Fiber Reinforced Concrete,* Japan Concrete Institute, 1983, pp. 45-51.

SECTION I

INTRODUCTION

A detailed literature review about fiber reinforced concrete (FRC) is given in an earlier report (11) submitted to the South Dakota Department of Transportation. Therefore only a brief summary with emphasis on synthetic fiber reinforced concrete is given here.

Concrete fiber composite technology has grown over the last three decades into a mature industry. Since the pioneering research on steel fiber reinforced concrete conducted in the United States in the 1960's, there has been substantial research and development activities throughout the world. A major advantage of using fiber-reinforced concrete is the improved toughness or residual load carrying ability after the first crack and enhanced fatigue strength. Additionally, a number of studies have shown that the impact resistance, of concrete can also improve significantly with the addition of fibers (1 to 9).

Combining the technical benefits and in place costs, fiber-reinforced concrete (FRC) was found to meet the prerequisites of Value Engineering particularly in airport and highway pavements, in bridge deck overlays, curtain walls, sewer pipes, cavitation or erosion resistant structures such as spillways, sluiceways, bridge piers and navigation locks, precast concrete products, earthquake resistance structures, missile silos and energy dissipaters. Fibers have also been used in shotcrete for rockfill stabilization, tunnel linings and dome structures. FRC had been used extensively in two areas: (a) overlays and repair of airport pavements and bridge decks, and (b) for repair of hydraulic structures in areas damaged by abrasion and cavitation (3, 4). In this report, an attempt is made to assess, evaluate and appreciate the behavior of the new polyolefin FRC. The performance of fresh concretes and the properties of hardened concretes with and without fibers are compared.

Plain concrete has two major deficiencies, a low tensile strength and a low strain at fracture. Presence of numerous microcracks reduces the tensile strength of concrete. It is the rapid propagation of these microcracks under applied stress that is responsible for the low tensile strength of the material. Fiber reinforced concrete increases the concrete ductility and its energy absorption capacity, as well as to improve overall durability. The primary role of the fibers in hardened concrete is to modify the cracking mechanism. By modifying the cracking mechanism, the macrocracking becomes microcracking. Smaller cracks result in reduced permeability and an enhanced ultimate cracking strain. The fibers are capable of carrying load across the crack.

The 3M Company, St. Paul, Minnesota, USA, has a series of synthetic polyolefin fibers with low aspect ratios. Like steel fibers, these fibers are available in various lengths and diameters and are added to improve the structural properties of concrete. These fibers can be mixed with concrete in large quantities, as much as 8 percent by volume without causing any balling, segregation or increase in air entrainment and entrapment. The amount of fibers that could be added depends on the length and diameter of the fibers. Extensive research (10, 11) has been done to determine the performance characteristics, fresh and hardened concrete properties of polyolefin fiber-reinforced concretes and mortars.

Polyolefin fiber reinforced concrete is one material that promises to provide many advantages over currently used steel and other polypropylene fibers while providing a practical approach to enhanced durability and cost effectiveness in concrete composites. Currently, polypropylene fibers are typically used at 0.1% to 0.3% by volume of concrete to reduce plastic shrinkage cracking. These fibers provide only minimal benefit to the mechanical properties of hardened concrete. Steel fiber, used more extensively in Europe, is typically incorporated in quantities up to 0.5% by volume of concrete, and while it does enhance the structural performance of hardened concrete, it poses other problems such as staining, inherent corrosion and potentially harmful protrusions.

Toughness is an important characteristic for which fiber reinforced concrete is noted. Under static loading, flexural toughness may be defined as the area under the load-deflection curve in flexure, which is the total energy absorbed prior to the complete failure of the specimen. The most important variable governing the toughness index of

FRC is the fiber efficiency. Other influences on the toughness index are the position of the crack, the fiber content and the distribution of the fibers. Fiber efficiency is controlled by the resistance of the fibers to pull out from the matrix, which is developed as a result of the bond strength at the fiber matrix interface. The advantage of pullout type of failure is that it is gradual and ductile, compared with a more rapid and possible catastrophic failure, which may occur if fibers are brittle and fail in tension with little or no elongation. The fiber pullout or fiber fracture depends on the yield strength of the fibers and the bond and anchorage between the matrix and the fiber (6).

Load deformation curves are a standardized method of quantifying the energy a beam absorbs during its load induced flexural deflection. The area under the curve represents the energy absorbed by the beam. Load deflection curves are drawn using the data from static flexure test. Unlike plain concrete, fiber reinforced concrete does not fail in a brittle and catastrophic manner at a clearly identifiable maximum load. Signs of significant material distress are visible, much before the load deformation curve becomes non-linear. Observation of a typical load deflection curve shows an appreciable improvement due to addition of fibers to concrete.

The toughness ratios and the residual strength factors (R-factors) obtained from the load deformation curves are good indicators of plastic behavior of a particular specimen. A value of 2 for I20/I10 and R-factors of 100 are indicators of perfect plastic behavior (7).

NMFRC has been placed using conventional equipment and procedures in applications such as a process tower slab, driveways, sidewalk and curb, pavements, and whitetoppings (11).

BACKGROUND

Due to a decaying infrastructure and tightening budget constraints, transportation engineers are challenged to rehabilitate existing facilities economically with an increase in performance. However, simultaneous improvements in cost and performance are unlikely unless new material technology can be exploited.

Polyolefin fiber reinforced concrete incorporates 50mm by 0.64 mm (2" by 0.025") fibers into the concrete mix. These fibers are longer and stronger than plastic fibers previously used to reinforce concrete, and a proprietary packaging technology enables rapid and uniform mixing into the concrete matrix at quantities up to 2% by volume. These volumes of fiber significantly alter the concrete's physical properties, especially toughness, ductility and resistance to shrinkage cracking. The improved properties make polyolefin fiber reinforced concrete an attractive material for bridge decks.

To be successful and long-lived, a bridge deck must be durable, resistant to fatigue, and cracks must remain tight to resist chloride intrusion. In the past, transportation agencies throughout the nation have found these requirements (maintaining acceptable crack widths) difficult to achieve. Several research projects have been undertaken to solve these problems, but with limited success. However, these challenges perfectly match polyolefin fiber reinforced concrete's characteristics.

The South Dakota Department of Transportation has sponsored research to investigate the properties and practicality of polyolefin fiber reinforced concrete. Through laboratory tests at the South Dakota School of Mines and Technology and construction of a segment of pavement, a bridge deck overlay, concrete barrier replacement, and a thin unbonded overlay of asphalt bridge approaches, the material proved to be workable and significantly more resistant to early cracking than ordinary concrete. The research results demonstrated increased fatigue capacity of 150%, crack width reductions below American Concrete Institute (ACI) recommendations for chloride intrusion, and skid resistant surface texture. In the opinion of the Department, the favorable research results warrant more widespread use of polyoelfin fiber reinforced concrete in other applications, including bridge decks.

PROJECT OBJECTIVE

The objective of this project is to accelerate the application of polyolefin fiber reinforced concrete through design, construction, evaluation, and documentation of a bridge deck replacement project. The project involves a complete deck replacement of the North bound 102m by 12m (330' by 40') curved steel girder structure carrying US85 over Interstate 90 near Spearfish, South Dakota. The entire deck and concrete barrier were replaced using concrete reinforced with 14.8 kg (25 lbs) of polyolefin fiber per cubic yard of concrete. The primary tasks of the project include;

Task 1 - Design the concrete mixes to be used.

Only minor concrete proportioning and mixing modifications were done to incorporate polyolefin fibers into the planned deck replacement of structure 41-095-059. The principal investigator prepared mix designs for a fiber addition rate of 14.8 kg/m^3 (25 lb/cu.yd) in the concrete mix. Trial mixes were prepared and tested for fresh and hardened concrete properties. Seven day testing was conducted for the determination of hardened concrete properties and projected 28-day design properties. Appropriate ASTM and ACI standard test methods were used to determine:

* slump
* vebe time
* air content
* unit weight
* yield
* concrete temperature
* finishability
* compressive strength
* modulus of elasticity
* flexural strength
* flexural fatigue strength
* endurance limit
* impact strength
* toughness indices
* flexural toughness factor by Japanese Standard
* equivalent flexural strength by Japanese Standard

Task 2 - Construct the deck replacement and barrier using polyolefin fiber reinforced concrete

Construction began in August 1995. Fiber bundles purchased from 3M were used in all deck and barrier replacement concrete. The deck was placed in two pours. The pour of one-half width occurred on August 15, and other half around September 15. Finally, barriers were placed. The principal investigator provided technical assistance and quality control testing during the construction.

Task 3 - Independently evaluate the constructability and performance of the polyolefin fiber reinforced concrete for the replacement deck and barrier.

The principal investigator observed the construction and performed tests necessary to assess the constructability of the replacement deck and barriers. Concrete samples were taken using procedures recommended by the American Society for Testing and Materials (ASTM) and ACI. Relevant weather conditions were recorded.

All fresh concrete properties listed in Task 1 were tested for the concrete actually used in construction. In addition, fiber content was determined by washing three random samples taken during each pour. Concrete prism and cylinder specimens made in the field were cured as per ASTM procedures and tested for all the hardened concrete properties listed in Task 2.

Following construction, the principal investigator surveyed the condition of the deck replacement and barrier at two weeks, one month, three months, six months, one year, and two years after construction. The condition survey was performed according to ACI 201.3R-86, *Guide for making a Condition Survey of Concrete Pavements* and ACI 201.1R-68. *Guide for Making a Condition Survey of Concrete in Service (Revised 1984).* Survey reports are comprehensive, with particular emphasis on measurement and characterization of cracks.

Task 4 - Prepare a technical report and implementation videotape documenting the design, construction process, and material performance.

At the conclusion of the two-year evaluation, the principal investigator submitted a brief summary of the structure's condition.

3M Company provided a professional quality videotape describing the material technology, construction activity, and early condition data within six months of the completion of construction. The videotape emphasized the technical aspects of the technology.

Task 5 - Conduct an open house for state transportation departments in FHWA Region8.

The South Dakota Department of Transportation hosted an open house at Spearfish, SD in conjunction with the construction activity. The one-day open house was held in early October 1995, after both halves of the deck were placed and before the placing of the concrete barriers. In addition to site inspection, the program included a technical presentation by the principal investigator.

Materials:

Fibers: The non-metallic fibers (Polyolefin fibers) were purchased from 3M, St. Paul, MN. The non-metallic fibers type 50/63 were 50.0 mm (2.00 inch) long and 0.63 mm (0.025 inch) diameter. There were about 20,000 fibers per pound. Several hundred individual fibers were wrapped together in approximately 50 mm (2 inch) diameter bundles, and were packaged 11.3 kg (25 lbs.) per box. Typical physical properties of 3M polyolefin Type 50/63 are given below.

Specific Gravity	0.91
Tensile Strength	275 MPa (40,000 psi)
Modulus of Elasticity	2647 MPa (384,000 psi)
Elongation at Break	15 - 17 %
Ignition Point	593°C (1100°F)
Melt Point	160°C (320°F)
Chemical and Salt Resistance	Excellent
Alkaline Resistance	Excellent
Electrical Conductivity	Low

Test Specimens

A number of test specimens were cast from all the mixtures. The following specimens were cast from each mix: 50 mm x 300 mm (6 x 12 - inch) cylinders for compressive strength and static modulus tests, 100 mm x 100 mm x 350 mm (4 x 4 x 14 - inch) beams for flexural strength, and toughness tests, 150 mm x 65 mm (6 x 2-1/2 - inch) discs for impact strength. The number of cylinders, beams and impact specimens varied depending upon the availability of the fresh concrete.

All concrete specimen molds were steel and delivered to the job site on the day prior to construction. The molds were well oiled. A portion of the fresh concrete from each mix was discharged into a wheelbarrow to carry out the fresh concrete tests and to make specimens. The specimens were covered with plastic sheets and remained at the job-site for a period of 24 hours. They were then taken to the Concrete Technology Laboratory, SDSM&T, where they were demolded and placed in a lime saturated water tank for curing. The specimens remained in the curing tank until they were tested at the appropriate age.

Mixture and Specimen Designation:

The following labeling procedure was used for all mixtures and specimens made from these mixtures:

DT - For trial mixes made in the SDSM&T laboratory

STC - For test cylinders made from concrete used for Trial Slab in Mix 1

STF - For test cylinders made from concrete used for Trial Slab- Mix 2

DC1- For test beams made from concrete used for Trial Slab – Mix 1

DF - For test cylinders made from concrete used for Trial Slab – Mix 2

SFBD – For concrete used in the Bridge deck

SFBAR – For concrete used in the Barrier

Figures and tables were also labeled as stated above.

QUALITY CONTROL TESTS

Tests for Fresh Concrete

The fresh concrete was tested for slump (ASTM C 143), air content (ASTM C 231), fresh concrete weight (ASTM C 138) and concrete temperature. The yield of the concrete was determined. The concrete from the unit weight container was washed and the fibers were separated and weighed to determine the actual fiber content in a cubic yard of concrete.

Tests for Hardened Concrete

Compressive Strength & Static Modulus

Cylinders were tested for compressive strength at ages 7 and 28 days according to ASTM C 39. Prior to the compression test the cylinders were also tested for the static modulus of elasticity (ASTM C 469) and for dry unit weight. The dry unit weight was obtained by dividing the weight of the specimen by the measured volume of the specimen.

Static Flexure Test

The beams were tested for static flexural strength (ASTM C 1018) at ages 7 and 28 days. According to ASTM C 1018, the beams were tested over a simply supported span of 300 mm (12 inch) and third point loading was applied to the beams. The deflection was measured at the mid-span by using a dial gage accurate to 0.00254 mm (0.0001 inch). The deflections were measured using a specially fabricated frame. It was possible to measure the actual deflections eliminating all extraneous deflections due to the crushing of concrete and testing machine deformations. This test was a deflection controlled test. The rate of deflection was kept in the range of 0.05 mm to 0.10 mm (0.002 to 0.004 inch) per minute as per ASTM C 1018. The loads were recorded at every 0.0254 mm (0.0001") increment in deflection until the first crack appeared after which the loads were recorded at regular intervals. The load corresponding to first crack and the maximum load reached were noted for each specimen. From the test results, load-deflection curves were drawn and ASTM toughness indices were calculated. The flexural toughness factor and equivalent flexural strength were also calculated using the Japanese standard method.

Impact Test

The specimens were tested for impact strength at an age of 28 days by the drop weight test method (ACI Committee 544). In this method, the equipment consisted of a standard manually operated 4.54 kg (10 lbs) weight with a 457 mm (18 inch) drop (compactor), a 63.5 mm (2-1/2 inch) diameter hardened steel ball, a flat steel base plate with a positioning bracket and four positioning lugs. The specimen was placed on the base plate with its rough surface facing upwards. The hard steel ball was placed on the top of the specimen and within the four positioning brackets. The compactor was placed with its base on the steel ball. The test was performed on a flat rigid surface to minimize the energy losses. The hammer was dropped consecutively, and the number of blows required to cause the first visible crack on the specimens was recorded. The impact resistance of the specimen to ultimate failure was also recorded. Ultimate failure is considered to be the number of blows required to open the crack sufficiently so that the pieces of specimen were touching at least three of the four positioning lugs on the base plate.

SECTION II

Research Task 1: Design the concrete mix to be used.

Conduct tests on the mix design to ensure desired properties are obtained.

The appropriate NMFRC mix proportion used for the bridge deck replacement project was determined. For this purpose seven trial mixes were done in the laboratory and the appropriate mix was determined, based on the desired fresh and hardened concrete properties of these mixes. The mix design was done for a polyolefin fiber addition of 14.8 kg/m^3 (25 lb./cu.yd) and to satisfy or exceed the SDDOT specifications which require a bridge deck concrete to have a 28 day compressive strength of 4500 psi, an air content of 5.5 to 7.5 %, and a slump of 1 to 3.5 inches.

Initially seven trial mixes were done with 3 additional mix designs done upon request by DOT engineers at a later date.The trial mix designations, date of casting, the W/C and W/(C+F), the mix proportions and fiber details are given in Table A1. The fresh concrete properties are given in Table A2. The 7-day compressive strength results are given in Table A3. All materials (coarse aggregate, fine aggregate, fly ash and air entraining agent) for the trial mixes as well as the actual bridge deck concrete were supplied by Birdsall Sand and Gravel. Based on the 7-day test results, mix DT10 was selected as the proposed mix design and was sent to DOT Engineers and the concrete supplier.

Cement	338 Kg/m^3 (570 lbs./cu.yd)	0.082 m^3 (2.90 cu.ft.)
Fly Ash	74 Kg/m^3 (125 lbs./cu.yd)	0.022 m^3 (0.80 cu.ft.)
Coarse Aggregate	794 Kg/m^3 (1340 lbs./cu.yd)	0.233 m^3 (7.98 cu.ft.)
Fine Aggregate	794 Kg/m^3 (1340 lbs./cu.yd)	0.227 m^3 (8.10 cu.ft.)
Fiber	14.8 Kg/m^3 (25 lbs./cu.yd)	0.013 m^3 (0.45 cu.ft.)
Water	184 Kg/m^3 (310 lbs./cu.yd)	0.141 m^3 (4.97 cu.ft.)
Air Content	6.5 % $\pm$ 1.0 %	0.050 m^3 (1.76 cu.ft.)
	Total	0.765 m^3 (27.00 cu.ft)

The dimensions of the polyolefin fibers were 50 mm (2 inches) long and 0.63 mm (25 mil) diameter.

The trial mixing was done on a hot day 29.4 °C (85 °F) and the concrete temperature varied from 25.9 to 28.8 °C (78.6 to 83.8 °F). For these conditions the slump obtained varied from 63.5 to 89.0 mm (2.5 to 3.5inches). The workability and finishability of the trial mixes were satisfactory. The air content obtained in the trial mixes was satisfactory. It varied from 5.5 to 6.4 % except for mix DT5 which had an air content of 4.3 %. If the concreting temperatures are different, then the slump will be different. If a slump of 63.5 to 89.0 mm (2.5 to 3.5inches) is not obtained in the field, then the concrete can be retempered in the field with water to achieve the required slump. This can be done before discharging the concrete into the hopper of the concrete pump. When retempered with water, the added quantity should not exceed 19.8 liters/m^3 (33 lbs./cu. yd.).

Hardened Concrete Properties of Trial Mixes

The 7 and 28 day compressive strengths for all mixes are compared in figure A1. The 7 day strengths varied from 25.46 Mpa(3695 psi) to 39.65 Mpa(5755 psi), mix DT5 which had a lower air content gave the highest strength. The first crack strength and the flexural strength (Modulus of Rupture) values are given in Table A4, and Fig. A2 and A3. The modulus of rupture values were slightly higher than the first crack strength, the difference was not significant. The modulus of rupture values were higher than expected when compared to plain concrete and it varied from 5.01 to 5.37 Mpa(740 to 780 psi).

The ASTM toughness properties, first crack toughness indices, I_5, I_{10}, I_{20}, the toughness ratios I_{10}/I_5 and I_{20}/I_{10} and the residual strength factors $R_{5,10}$ and $R_{10,20}$ are given in Table A5 and in Figs A4, A5, A6 and A9. These results showed positively that the addition of polyolefin fibers had increased the toughness of the concrete. Higher R-values indicate higher ductile behavior. The calculated Japanese Concrete Institute (JCI) flexural toughness factor and equivalent flexural strengths are given in Table A6 and Fig. A7 and A8 respectively. These results also confirm the considerable increase in toughness and ductility of the concrete due to the addition of polyolefin fibers.

Preconstruction Meeting

At the request of the Contractor, a preconstruction meeting was held on July 24, 1995 at the office of the Contractor, Heavy Constructions, in Rapid City, to discuss the change order provisions. The Contractor expressed apprehension about the workability of NMFRC. He also had concerns about the pumping, placing, consolidation, finishing and tining operations with NMFRC. Therefore he requested a demonstration placement of the deck slab.

Trial Placement

The trial placement of the slab was done on September 6, 1995, at the DOT yard in Spearfish, which is very close to the bridge deck to be constructed. It was a windy day and the temperature varied from 15.5 to 18.3 °C (60 to 65 °F). Using the recommended mixture proportions, the concrete was mixed at the Birdsall Sand and Gravel Plant in Spearfish, which was close to the DOT yard and the bridge. When all water including the water intended for retempering was added, the slump of the concrete before the addition of the fibers was 101 mm (4 inches) and the air content was about 10 percent. Then the fibers were added and mixed. The truck was then taken to the DOT yard. The slump before discharging was 19 mm (0.75 inch). Therefore the concrete was retempered with water 15 liters/m^3 (3 gallons per cubic yard) before discharging into the pump hopper. The slump and air content were determined after the concrete was pumped into place. The slump measured 82.5 mm (3.25 inches) and the air content was 8.8 percent. The details are given in Table B1, Appendix A.

When the trial mix was done in the lab, there was a slump of 76.2 mm (3 inches) before adding the retempering water, inspite of a hot day with concrete temperature of 27.5 °C (82 °F). However for the same mix proportions, the slump was only about 12.7 mm (0.5 inch) at the plant. The difference might be because, it was extremely hot for several days prior to the trial placement causing the aggregates' moisture content to be less than "saturated surface dry". Then with cooler temperatures on the day of the placement, the aggregates' moisture had already been reduced and may not have been taken into consideration. The pumping was easy and the consolidation and finishing operations were performed without any difficulty. The floating, brooming and tining were done without any difficulty.

Hardened properties for concrete used for the trial slabs, compressive strength, static modulus and dry weight results are given in Table B2, Appendix A. The 7 and 28 day compressive strengths were lower than obtained in the trial mixes (Fig. A1), because concrete was retempered with more water. The 7-day strengths varied from 23.56 to 24.36 Mpa (3420 to 3535 psi) and the 28-day strengths were 31.11 Mpa (4515) and 31.49 Mpa (4570 psi). The unit weights were also lower than those of trial mixes. The first crack strengths and flexural strengths are given in Table B3, Appendix A. These values are compared with the trial mixes in Fig. A2 and A3 in the Appendix A. The first crack strength and flexural strength were lower than those of trial mixes, the same trend as 9in the case of compressive strength.

The ASTM toughness properties are given in Table B4, Appendix A and the JCI toughness values are given in Table B5, Appendix. These values are compared with those of trial mixes in Fig. A4 to A9. Both ASTM and JCI values are lower for the concrete used in the trial slab. However the difference was not significant.

Additional Trial Mixes:

Since the calculated yield for the first seven trial mixes was 0.765 m^3 (27 ft^3) excluding the volume of the fibers, DOT engineers suggested that the yield be calculated including the fiber volume. Therefore, three additional trial mixes were done which accounted for the 0.013 m^3 (0.45 ft^3) fiber volume. The coarse and the fine aggregates were reduced to obtain a calculated yield of 0.763 m^3 (26.95 ft^3) including fibers. Two of the three additional mixes were done with coarse to fine aggregates ratios of 55/45 based on weight with the third having a 50/50 aggregate ratio based on weight which was similar to the first seven trial mixes. These three new mixes were done at the SDSM&T Laboratory on September 8, 1995. The details of the additional mixes are given in Tables C1 to C3 in Appendix A.

The trial mixes had shown that the change in coarse to fine aggregate ratio did not affect the slump significantly. Mix DT-10 with 50 % coarse aggregate and 50 % fine aggregate had a slump of 3 inches and mix DT-8 with 55 % coarse aggregate and 45 % fine aggregate had a slump of 2.75 inches. Both mixes had the same amount of water. The same slump was obtained as in earlier testing (Mix DT-4).

The hardened concrete properties of the trial mixes, compressive strength, unit weight and the static modulus are given in Table C3 in Appendix A. Mixes DT8 and

DT10 gave higher 7 and 28 day strengths as compared in Fig. A1. The 7-day strengths were 29.87 Mpa (4335 psi) and 28.35 Mpa (4115 psi) respectively for mixes DT8 and DT10. The corresponding 28-day strengths were 41.37 Mpa (6005 psi) and 40.79 Mpa (5920 psi).

Based on the 7 day test results from the 10 trial mixes, mix DT10 was selected as the proposed mix design and was sent to DOT engineers and the concrete supplier.

SECTION III

Research Task 2: Construct the deck replacement and barrier using polyolefin fiber reinforced concrete

Deck Slab Construction

The east lane of the NMFRC bridge deck placement was done on September 22, 1995, and the second placement was done on September 26, 1995. On September 22, the placement started at 8:30 AM and the temperature was 10 °C (50°F) and the humidity was 30 percent. When the placement was completed about noon, the temperature was 29.4 °C (85°F) and the relative humidity was 15 percent. Therefore the weather conditions were satisfactory during the construction of the deck slab.

Concrete was mixed at Birdsall Sand and Gravel Plant in Spearfish, which is close to the bridge site. The same recommended mixture proportions were used for both lanes. Concrete was mixed and transported in trucks and delivered to the hopper of the pump. The air content and slump were checked. In the beginning the contractor had difficulty estimating the correct amount of air entraining agent to be added because of the pumping of the concrete . For the first few trucks the air content was adjusted at site, to meet the specified air content and slump. Later, the contractor was able to deliver the concrete meeting the specified air content and slump.

The pumping, placing, consolidation, finishing and tining operations went smoothly without any problems. The same procedures as used in the trial slab construction were used in the construction of the bridge deck slab.

The west lane of the bridge deck placement was done on September 26, 1995. When the placement started at about 6:30 AM, the temperature was 10 °C (50°F) and the relative humidity was 35 percent. Towards the end of the placement, the temperature was 29.4 °C (85°F) and the relative humidity 10 percent. The same mixture proportions and the same procedures as per the first placement were used for mixing, transporting, pumping, placing, consolidation, finishing, and tining operations. No problems were encountered in the beginning until the middle of the placement two trucks delivered concrete in which a few fiber bundles were not opened. These two trucks had a higher slump which resulted in less shearing action causing the bundles not to break. Two minutes of additional mixing corrected this problem. The rest of the concreting was done without any problems. In general, the fibers were well mixed, and they were also uniformly distributed. In my opinion, no additional effort was needed on the part of the contractor, for transporting, placing and finishing operations. However, some additional expense was needed to add the fibers and mix in the concrete, when compared to plain concrete without fibers.

Barrier Construction

Since the contractor did not have enough forms, each barrier was constructed half at a time. As a result the bridge required four barrier placements. For the 1st and 2nd placements, the concrete was pumped because the approach slab had not attained the required strength, which prevented delivery trucks from driving on the bridge deck. The 3rd and 4th placements were done without the use of a concrete pump. The contractor preferred to use a low slump concrete, about 50.8 to 63.5 mm (2 to 2.5 inches). Hence there was difficulty in placing and vibration. It had to be vibrated more and this slowed the construction of the barrier.

In my opinion, for a thin, heavily reinforced section, such as the barrier, the concrete should have a slump of 114.3 to 127.0 mm (4.5 to 5 inches). Then a minimum amount of vibration will be needed and placement will be easier. This higher slump can be achieved without a reduction in compressive strength by adding an appropriate amount of superplasticizer.

Control Tests

During both bridge deck concrete placements and once during the construction of the barrier, control tests, such as concrete temperature, air content, slump, fresh concrete unit weights, actual fiber content were conducted at the site using concrete sampled at random from the discharge end of the pump. Beam and cylinder specimens were cast for testing the hardened concrete properties. These results of the deck slab concrete tests are tabulated as shown in Tables D1 to D6 Appendix B. The test results for the concrete used in the barrier construction are given in Tables E1 to E6 in Appendix B.

Properties of the concrete used in the Bridge Deck

The fresh concrete properties are given in Table D1, and the number of specimens made in the field are given in Table D2, Appendix B. The ambient temperature varied from 10 ^{0}C (50 ^{0}F) to 29.4 ^{0}C (85 ^{0}F) and the relative humidity varied from 5 to 35%. The concrete temperature varied from 14.1 ^{0}C (57.3 ^{0}F) to 19.9 ^{0}C (67.9 ^{0}F). Initially the air content was 3.8% and later it was satisfactory, varying from 5.5 to 6.8%. The actual fiber contents obtained from the fiber concrete were close to the specified value 14.9 kg/m^3 (25.2 lbs/cu. yd.) and 15.1 kg/m^3 (25.4 lbs/cu. yd.). This indicated that the mixing was good and there was very good uniform distribution of the fibers.

The hardened concrete properties, the 7 and 28-day dry unit weight, static modulus, and compressive strength results are given in Table D3 and Fig. B1, in Appendix B. The 7 and 28-day compressive strengths were respectively 30.80 Mpa (4470 psi) and 40.13 Mpa (5825 psi) for sample 1 and 25.66 Mpa (3725 psi) and 36.76 Mpa (5336 psi) for sample 2. These strengths were much higher than the minimum specified 28 day strength of 31 Mpa (4500 psi).

The 7 and 28-days first crack strength and the flexural strengths are given in Table D4 and Fig. B2 and B3, Appendix B. The 7-day first crack strengths were 4.82 Mpa (700 psi) and 4.22 Mpa (613 psi) for samples 1 and 2. The corresponding 28-day flexural strengths were 6.06 Mpa (880 psi) and 5.58 Mpa (810 psi). These values were considerably higher than the expected values anticipated for plain concrete.

The ASTM toughness values and residual strength factors are given in Table D5, and Fig. B4, B6 and B9, in Appendix B. The JCI toughness factors and equivalent flexual strengths are given in Table D6 and Fig. B7, and B8, Appendix B.

Both the ASTM and JCI toughness indicators showed that the deck concrete had high toughness and ductility. The first crack and final failure impact strengths are given in Table D7 and in Fig. B10, in Appendix B. This concrete had a very high impact resistance, the average number of blows for the first crack was 82 and the number of blows for final failure was 516.

Properties of the concrete used for the barrier

The fresh concrete properties are given in Table E1, Appendix B. The ambient temperature was 10 ^{0}C (50 ^{0}F) and the relative humidity was 60 percent. The concrete temperature was 14 ^{0}C (57.2 ^{0}F). The air content was 7 %, which was within the specified limit. The slump was low only 54 mm (2 inches). Therefore there was difficulty in placing and consolidating in the heavily reinforced barrier.

The hardened concrete properties, unit weight, static modulus, and compressive strength are given in Table E3, and Fig. B1, Appendix B. The 28-day compressive strength was above the specified value, 33.97 Mpa (4930 psi). This was lower than the strength of the deck concrete (Fig. B1). The first crack and flexural strengths are given in

Table E4 and Fig. B2 and B3, Appendix B. These values are above the expected values, however lower than the deck concrete (Fig. B2 and B3).

The ASTM and JCI toughness factors are given in Tables E5 and E6, and Figs. B4 to B9, Appendix B. These toughness characteristics indicated that the addition of fibers had considerably increased the toughness and ductility of the concrete.

SECTION IV

Research Task 3: Independently evaluate the constructability and performance of the polyolefin fiber reinforced concrete for the replacement deck and barrier.

Following the construction of the bridge deck and the barrier walls using the NMFRC, the performance of the bridge deck was evaluated. Inspections had been done on the bridge deck at predetermined intervals of time. During the inspections, cracks were identified on the top and bottom of the deck's surface and the barrier walls. During each inspection, each crack was counted and the crack widths recorded. The width of the cracks was measured by a crack comparator, which can measure the width accurate to 0.05 mm (0.002 in.). The inspections had been done on September 26, October 26, November 12, December 18, 1995, March 13, June 3, 4, September 8, 1996, June 16, and on September 6, 1997. The final inspection of the bridge deck was done on November 19, 1997.

The ACI Committee 224 report on cracking has recommended that the maximum crack width that can be tolerated under the environmental conditions at the bridge (exposed surface subjected to deicing chemicals) is 0.18 mm (0.007 inches). Therefore the performance of the bridge will be determined by comparing visible cracks and their respective widths to ACI Committee 224's recommended maximum tolerable crack width for preventing the intrusion of deicing chemicals.

Bridge deck slab - Top surface

No cracks observed on the top of the bridge deck in the 1995 and March 13, 1996 inspections. No spalling, scaling or any other distress had been observed. Fibers were observed on the surface but they were well bonded to the concrete and unlike the steel fibers did not pose any hazardous threat. These exposed fibers are expected to wear out with time due to the abrasion of the traffic on it.

On March 13, 1996, clumps of fibers were found exposed in three locations. However they were still bonded to the concrete. These are unopened bundles mixed in concrete. These three clumps were found in the same location where unopened or partially opened bundles were noticed in the concrete during construction. At the time of construction, most of the unopened or partially opened bundles were thrown out. A few must have been overlooked. Unopened or partially opened bundle occurred only in two truck loads of concrete and the concrete was corrected for the rest of the trucks. Two scratch lines (about 1 mm deep and 10 mm wide) were found on the surface during this inspection. They were 4.57 to 6.10 m (15 to 20 feet) long. These scratches must have been made by heavy equipment, such as snow removal equipment.

Six hairline cracks were observed on the untined edges near the barrier upon inspection on June 3, 1996. Only one crack was 0.10 mm wide and all other cracks were less than 0.08 mm wide. All the cracks were about 0.3 m (1.0 ft) long. There was no distress or any other form of damage noticed.

On September 8, 1996, many hairline cracks on the deck slab surface were observed upon inspection. Cracks with widths less than 0.1 mm (0.0039 inches) are termed as hairline cracks in this report. Most of the cracks originated and extended from the region between the barrier and the tined surface of the deck slab. The crack locations and width of the crack have been tabulated. (Refer to Tables F3 and F3a).

During the inspection of the bridge deck slab done on June 16, 1997 a total of 44 cracks were found on the East side of the top surface of the slab upon careful inspection. Only 12 of these cracks were above 0.18mm (0.007inch) in width. Most of the cracks were found to be hairline cracks. The crack widths have been tabulated and compared to the previous inspection in Appendix C. The west side of the slab could not be inspected on the top surface because of the presence of sand on the entire length of the slab.

On September 6, 1997, the bridge deck was inspected for new cracks, and an increase in the widths of the old cracks. The locations and the widths of the old and new cracks are given in Tables F in Appendix C.

The final inspection of the bridge deck was done on November 19, 1997. The inspection of the bridge deck on both the lanes was not possible because of the accumulation of snow along the bridge deck. The bottom surface of the bridge deck was observed using binoculars, no new cracks were observed.

Barrier

During the September 26, 1995 inspection, two hairline cracks less than 0.1 mm (0.0039 in) wide were observed in the constructed part of the barrier. Subsequent inspections have revealed more hairline cracks, most of which are barely visible. On a detailed and careful inspection using magnifying lens on December 18, 1995, three hairline cracks were observed on the east side barrier. Crack widths were measured and one crack was found to be of 0.1mm (0.0039 inch) width and the other two were 0.08 mm (0.003 inch) width. All these cracks were shrinkage cracks and the width of these cracks was less than 0.18 mm (0.007 inch) the ACI Committee 224 recommended maximum tolerable crack width under the environmental conditions at the bridge. According to the American Concrete Institute Committee 224 on cracking if the cracks are narrower than recommended widths, then it can be assumed that the possibility of corrosion of the reinforcement due to moisture penetration is negligible and the concrete is durable.

During the inspection on March 13, 1996 the surface was wet due to rain in the morning. No crack was noticed on the inner faces of both the barriers. The hairline cracks noticed during the previous inspection could not be located because of the wet condition of the surface. Using a powerful binocular, outer surfaces of the barriers were inspected. No cracks could be located on the west side barrier. No new cracks were observed on the east side barrier, the cracks which had been located in the previous inspection on the outer surface were noticed and were near the bottom of the barrier. They did not extend higher into the barrier.

Upon inspection on June 3,4, 1996 the barriers were found to have been given a " special surface finish". However the coating did not appear to obstruct the visibility of the cracks including the hairline cracks. Twenty five hairline cracks were observed. All cracks were less than 0.1mm in width. The barrier had been painted when inspected on September 8, 1996. Most of the old cracks were clearly visible. Some new cracks were also observed. The crack locations and crack widths have been tabulated in Table F, Appendix C.

The inspection done on June 16, 1997 showed the presence of many new hairline cracks. There were 126 cracks found on the East side barrier and a total of 106 cracks were found on the West side barrier. Only 2 of these cracks were above 0.18mm (0.007 inch) in width. Most of the cracks were less than 0.10mm (0.004) wide. The cracks have been tabulated and compared to the previous inspection in Table F in the Appendix C.

On September 6, 1997, the barriers were inspected for new cracks, and an increase in the widths of the old cracks. The locations and the widths of the old and new cracks are given in Tables F in Appendix C. Spalling of the polymer coated paint on the jersey barrier, about 4-5 sq.ft., was observed at the center span of the east side barrier.

The final inspection of the bridge deck was done on November 19, 1997. The barriers were carefully inspected for new cracks and increased widths of the old cracks. No substantial increase compared to the previous inspection, was observed in this inspection. The location and the widths of the cracks in comparison with the previous inspection are given in Table F, Appendix C.

Bridge Deck Slab Bottom side

Snoopers were used to inspect the bottom side of the bridge deck. On December 18, 1995, 8 cracks were observed on the bottom side of the bridge deck slab. The cracks on the bottom surface appear to be more frequent on the west side as compared to the east. This resulted from the deck being placed in two passes (each lane separately) with the shorter inside lane of the curve being placed first. Six of the cracks were on the cantilevered part of the bridge deck on the east side. Three of them were wider than 0.18 mm (0.007 inch) while three were less than 0.18 mm (0.007 inch) in width. Only three cracks were on the main slab, two of them just above the two end pylon supports, the third one being in the middle of the bridge and 381 mm (15 inch) long and 0.2 mm (0.0079 inch) wide. No crack extended over the entire width of the slab. There was white efflorescence in all the cracks which enhanced the visibility of the cracks thus giving the cracks a wider and longer appearance. All the cracks were perpendicular to the direction of the traffic and parallel to the main reinforcement. Therefore the cracks were not induced due to any bending action. These cracks are due to restrained shrinkage. These cracks are shown in sketches in Appendix C

Upon inspection on March 13, 1996, the previously recorded cracks did not seem to widen or extend further. On June 3, 4, 1996 additional cracks were noticed on the bottom side of the bridge deck slab. The snooper was not used during this inspection. No new crack was observed with a powerful set of binoculars on September 8, 1996. The cracks noticed on the first inspection (December 18, 1995) showed white efflorescence, while the rest observed on the June 3,4, 1996 inspection did not show white efflorescence. The length and width of all the observed cracks have been noted and are given in Table F. The period in which a particular crack was noticed has also been mentioned in the tables. Sketches (Appendix C) also have been drawn to indicate these cracks.

Careful inspection on June 16, 1997 with the help of a snooper showed the presence of many hairline cracks. It was not possible to measure some of the previously located cracks because of the difficulty and risk involved in the process. Many new cracks were located and measured. Some of the new cracks are found to be perpendicular to the main reinforcement and parallel to the traffic, but are of negligible widths. The findings of this inspection are shown in sketches in Appendix C. The newly located cracks have also been included in the sketches drawn to show their location.

On September 6, 1997, the bridge deck bottom surface was carefully observed using binoculars. No new cracks were observed during the inspection.

The final inspection was done on November 19, 1997. The bridge deck bottom surface was observed for any new cracks or substantial increase in the old cracks. No new cracks or increased widths of the old cracks were observed during the inspection. The snooper was not used during the inspection; however a powerful set of binoculars was used.

Research Task 4: Prepare a technical report and implementation videotape documenting the design, construction process, and material performance.

Quarterly progress reports (nine) were submitted outlining the construction and early evaluation phases of the project. As the conclusion of the two-year evaluation, this final report gives a detailed description of the structure's condition.

The 3M company with the assistance of the PI has made two professional quality videotapes; one describing the material technology, construction activity and early condition data. The second video showed all the tests performed on the hardened concrete with explanation of the test procedure and results. The video was taken at the Concrete Technology laboratory, SDSM&T. The videotapes were reviewed by the PI and SDDOT. The final versions of the videotapes were submitted to the SDDOT. They are available from the PI, 3M Company, and SDDOT. The PI had shown these video tapes in numerous professional society meetings including TRB, ACI, and ASCE meetings, national and international conferences and workshops.

Reasearch Task 5: Conduct an open house for state transportation departments in FHWA Region 8.

The South Dakota Department of Transportation, 3M corporation, and the South Dakota School of Mines and Technology sponsored the open house for the Federal Highway Administration's Priority Technologies Program. The Open House was conducted on Thirsday, October 12, 1995 from 8.30 am through mid-afternoon at the Northern Hills Ramada Inn on Interstate 90 four miles east of Spearfish, SD. The deck replacement on the US85 interchange structure over I90 provided an excellent demonstration of an innovative technology that can be readily used by state, local and federal transportation agencies, design and construction consultants, concrete constructors and suppliers, and academics.

The Open House included sessions such as: 'Polyolefin Fiber Basics' by 3M Corporation, 'Applications of Polyolefin Fiber for Reinforcing concrete by Dr. V. Ramakrishnan, SDSM&T, the 'SDDOT Interest in Polyolefin Fiber Reinforced Concrete' by SDDOT, 'Construction Issues' by SDDOT & Heavy Constructors, Bridge Deck Site Inspection, and 'Other Application of Polyolefin Fiber Reinforced Concrete' by 3M Corporation.

Conclusions

Based on the observations made during the trial mixing, the actual construction of the bridge deck slab and barriers, analysis of the test results, and evaluation of the performance of the polyolefin fiber reinforced concrete, the following conclusions are made:

1. It is possible to incorporate the newly developed non-metallic polyolefin fibers in concrete at 14.8 kg/m^3 (25 lbs/cu.yd.) without causing any balling, clogging and segregation.
2. The adding of the fibers did not cause any additional bleeding or cause any other construction problems during mixing, pumping, placing, consolidating, finishing and tining operations.
3. Compared to plain concrete, additional mixing time (about 5 minutes) is needed for the proper mixing and uniform distribution of the fibers. If not adequately mixed, the bundles would not open fully.
4. It is possible to achieve the specified workability and finishablity without any addition of superplasticizers and without exceeding the SDDOT specified w/c ratio.
5. It is easy to pump NMFRC with the same equipment without modifications used for pumping plain concrete.
6. The addition of polyolefin fibers at 14.8 kg/m^3 (25 lbs/cu.yd.) enhanced the structural properties of concrete. There was an increase in the flexural strength, and a considerable increase in toughness, impact, and post-crack load-carrying capacity.
7. The same construction techniques and equipment without modifications could be used in the construction of bridge deck slabs and barriers. The consolidation, finishing and tining operations were the same as for plain concrete.

Based on the periodic inspections over a period of two years, and final evaluation of the condition survey, the following conclusions are made:

1. The post construction performances of the deck slab and barriers were satisfactory. Once the cracks formed, the polyolefin fibers helped to contain the crack propagation and to restrict the widening of the cracks.

2. In the barrier, the addition of fibers reduced the average shrinkage crack widths. However, there was a larger number of uniformly distributed thinner cracks in the NMFRC as compared to a fewer number of wider cracks for plain concrete. The NMFRC gives a more desirable crack distribution. In the fiber barriers, only a few cracks were wider than 0.18mm (0.007 inch), which is ACI Committee 224's recommendation for maximum tolerable crack width for the exposure conditions prevalent at bridge sites. Reduced crack widths would increase the durability of the structure.
3. A visual comparison of this bridge and the nearby bridge constructed a year earlier with plain concrete had shown that the NMFRC deck had less number of visual transverse and longitudinal cracks. The actual counting of the number of cracks and measuring the lengths and widths of the cracks in the companion bridge were not done.

Recommendations

- When high performance concrete is desired, the utilization of polyolefin fiber reinforcement is one of the several enhancements that can be made to bridge deck and Jersey barrier concrete to improve performance.
- Fiber addition rates for bridge decks could be optimized to some rate other than 14.8 kg/m^3 (25 lb/yd^3) so that no restrained shrinkage crack would exceed ACI Committee 224's recommended maximum for deicing chemicals (0.18 mm = 0.007 inches).
- Fiber addition rates for Jersey barriers could be optimized to some rate other than 14.8 kg/m^3 (25 lb/yd^3) so that no shrinkage crack would exceed ACI Committee 224's recommended maximum for deicing chemicals (0.18 mm = 0.007 inches)

Limitation

The addition of polyolefin fibers at 14.8 kg/m^3 (25 lbs/cu.yd.) almost doubled the unit price of concrete. However, the enhanced structural properties and the resulting better long-term performance of the structure could justify the use of polyolefin fibers

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APPENDIX – A

Details of the Laboratory Trial mixes and concrete used for Trial Slab

Mix Designation	Description
DT 1-7	Trial Mixes made in SDSM&T laboratory
DT 8-10	Additional Trial Mixes made in SDSM&T laboratory
STC 1-3	Test Cylinders made from concrete used for Trial Slab in Mix 1
STF 1-3	Test Cylinders made from concrete used for Trial Slab in Mix 2
DC 1-4	Test beams made from concrete used for Trial Slab in Mix 1
DF 1-5	Test beams made from concrete used for Trial Slab in Mix 2

Table A1: Mixture Proportions for Trial Mixes

Mixture Designation & Date of Casting	W/C Ratio	W/(C+F) Ratio	Mixture Proportions Kg/m^3 (lbs/cubic yard)					Fiber Dosage Kg/m^3 (lbs/cu.yd)	AEA mL/m^3 (oz/cu.yd)
			Cement	Coarse Aggregate	Fine Aggregate	Fly Ash	Water		
DT-1 08/16/95	0.53	0.43	331.7 (559.4)	851.3 (1435.5)	851.3 (1435.5)	73.4 (123.8)	174.4 (294.1)	14.7 (24.7) (1.65%)	460 (11.9)
DT-2 08/16/95	0.53	0.43	331.7 (559.4)	851.3 (1435.5)	851.3 (1435.5)	73.4 (123.8)	174.4 (294.1)	14.7 (24.7) (1.65%)	460 (11.9)
DT-3 08/16/95	0.55	0.45	326.9 (551.2)	838.8 (1414.5)	838.8 (1414.5)	72.3 (122.0)	179.6 (302.9)	14.5 (24.4) (1.62%)	453 (11.7)
DT-4 08/16/95	0.56	0.46	332.3 (560.4)	830.7 (1400.9)	830.7 (1400.9)	71.6 (121.0)	185.6 (313.0)	14.3 (24.1) (1.61%)	449 (11.6)
DT-5 08/19/95	0.42	0.34	357.7 (603.1)	865.8 (1460.0)	865.8 (1460.0)	78.5 (132.3)	149.0 (251.3)	15.7 (26.4) (1.76%)	492 (12.7)
DT-6 08/19/95	0.54	0.44	341.4 (575.7)	826.4 (1393.6)	826.4 (1393.6)	74.9 (126.3)	185.0 (312.0)	15.0 (25.2) (1.68%)	470 (12.1)
DT-7 08/19/95	0.61	0.50	334.7 (564.3)	810.1 (1366.0)	810.1 (1366.0)	73.4 (123.8)	204.3 (344.6)	14.7 (24.7) (1.65%)	460 (11.9)

Fiber description : 50mm (2 inches) long 63mm (25 mil) straight polyolefin fibers.

Table A2: Fresh Concrete Properties for Trial Mixes

Mixture #	Room Temp. Humidity °C (°F)	(%)	Concrete Temp. °C (°F)	Unit Weight Kg/m³ (pcf)	Calculated Volume cu.m (cu.ft.)	Air Content %	Slump mm (inches)
DT-1	26.7 (80)	40	27.0 (80.6)	2342.9 (146.3)	0.057 (2.0)	5.5	25 (1.00)
DT-2	29.4 (85)	40	28.3 (82.9)	2349.5 (146.7)	0.057 (2.0)	6.4	38 (1.50)
DT-3	29.4 (85)	50	28.8 (83.8)	2309.1 (144.2)	0.058 (2.1)	6.4	44 (1.75)
DT-4	29.4 (85)	50	28.8 (83.8)	2323.1 (145.0)	0.058 (2.1)	5.8	64 (2.50)
DT-5	26.7 (80)	30	25.9 (78.6)	2342.9 (146.3)	0.053 (1.9)	4.3	13 (0.50)
DT-6	26.7 (80)	30	27.2 (80.9)	2316.5 (144.6)	0.056 (2.0)	5.8	38 (1.50)
DT-7	26.7 (80)	30	28.2 (82.7)	2217.5 (138.4)	0.057 (2.0)	6.1	70 (2.75)

Table A3: Hardened Concrete Properties for Trial Mixes

Specimen #	Age (days)	Length mm (inches)	Diameter mm (inches)	Unit Weight Kg/m^3 (pcf)	Compressive Strength MPa (psi)
DT2-C1	7	306.5 (12.065)	151.1 (5.950)	2359.5 (147.3)	30.35 (4405)
DT2-C2	7	308.9 (12.160)	151.5 (5.963)	2322.8 (145.0)	28.99 (4207)
DT2-C6	7	307.7 (12.115)	151.4 (5.960)	2333.9 (145.7)	29.51 (4283)
				Average	**29.63 (4300)**
DT3-C1	7	304.6 (11.993)	151.4 (5.960)	2324.6 (145.1)	29.02 (4212)
DT3-C2	7	306.7 (12.074)	151.4 (5.960)	2284.3 (142.6)	29.51 (4283)
				Average	**29.28 (4250)**
DT4-C1	7	308.2 (12.135)	151.5 (5.963)	2335.8 (145.8)	29.61 (4297)
DT4-C2	7	307.6 (12.112)	151.5 (5.965)	2314.0 (144.5)	29.33 (4258)
				Average	**29.49 (4280)**
DT5-C1	7	304.2 (11.975)	151.1 (5.947)	2388.1 (149.1)	39.69 (5760)
DT5-C2	7	304.9 (12.005)	151.4 (5.962)	2378.4 (148.5)	39.73 (5766)
DT5-C3	7	305.2 (12.015)	151.2 (5.953)	2392.4 (149.4)	39.49 (5731)
				Average	**39.65 (5755)**
DT6-C1	7	309.6 (12.190)	151.0 (5.945)	2331.3 (145.5)	29.78 (4323)
DT6-C2	7	305.9 (12.045)	151.0 (5.945)	2318.00 (144.7)	29.78 (4323)
				Average	**29.80 (4325)**
DT7-C1	7	306.3 (12.060)	150.9 (5.940)	2302.7 (143.8)	25.49 (3699)
DT7-C2	7	307.5 (12.105)	151.4 (5.960)	2286.8 (142.8)	25.44 (3692)
				Average	**25.46 (3695)**

Table A3: Hardened Concrete Properties for Trial Mixes (Contd…)

Specimen #	Age (days)	Length mm (inches)	Diameter mm (inches)	Unit Weight Kg/m^3 (pcf)	Static Modulus MPa (psi)	Compressive Strength MPa (psi)
DT2-C3	28	309.4 (12.180)	152.0 (5.985)	2302.5 (143.7)	36777 (5.33×10^6)	39.20 (5690)
DT2-C4	28	308.5 (12.145)	152.1 (5.987)	2307.5 (144.1)	36777 (5.33×10^6)	39.89 (5790)
DT2-C5	28	310.00 (12.204)	152.1 (5.987)	2304.5 (143.9)	36777 (5.33×10^6)	40.03 (5810)
					Average	**39.72 (5765)**
DT3-C3	28	308.7 (12.155)	152.2 (5.991)	2294.2 (143.2)	33879 (4.91×10^6)	37.38 (5570)
					Average	**37.38 (5570)**
DT4-C3	28	307.3 (12.100)	152.1 (5.987)	2299.8 (143.6)	29394 (4.26×10^6)	38.69 (5615)
DT4-C4	28	309.3 (12.175)	151.7 (5.973)	2288.1 (142.8)	29532 (4.28×10^6)	37.38 (5570)
DT4-C5	28	308.7 (12.152)	151.8 (5.975)	2274.7 (142.0)	29532 (4.28×10^6)	38.45 (5580)
					Average	**38.52 (5590)**
DT5-C4	28	307.6 (12.111)	152.4 (5.999)	2345.5 (146.4)	36639 (5.31×10^6)	49.99 (7255)
DT5-C5	28	306.1 (12.050)	151.8 (5.975)	2351.2 (146.8)	36915 (5.35×10^6)	50.88 (7385)
DT5-C6	28	306.1 (12.050)	151.9 (5.980)	2355.2 (147.0)	36846 (5.34×10^6)	50.54 (7335)
					Average	**50.47 (7325)**
DT6-C3	28	308.6 (12.150)	151.8 (5.975)	2307.5 (144.1)	29532 (4.28×10^6)	41.03 (5955)
DT6-C4	28	309.9 (12.200)	152.0 (5.985)	2306.7 (144.0)	29463 (4.27×10^6)	41.65 (6045)
DT6-C5	28	308.9 (12.162)	152.0 (5.984)	2290.7 (143.0)	29463 (4.27×10^6)	41.17 (5975)
					Average	**41.27 (5990)**
DT7-C3	28	305.8 (12.040)	152.0 (5.983)	2265.5 (141.4)	29463 (4.27×10^6)	33.07 (4800)
DT7-C4	28	308.9 (12.160)	152.2 (5.990)	2269.9 (141.7)	29394 (4.26×10^6)	33.24 (4825)
					Average	**33.15 (4815)**

Table A4: First Crack Strength and Maximum Flexural Strength for Trial Mixes

Specimen #	Age (Days)	First Crack Load Kg (lbs)	First Crack Deflection mm (inches)	First Crack Stress Mpa (psi)	Maximum Load Kg (lbs)	Flexural Strength Mpa (psi)
DT2-B1	28	1752 (3860)	0.005 (0.0002)	4.86 (705)	1752 (3860)	4.86 (705)
DT2-B2	28	1911 (4210)	0.025 (0.0010)	5.20 (755)	1911 (4210)	5.20 (755)
DT2-B3	28	1906 (4200)	0.015 (0.0006)	5.11 (741)	2039 (4490)	5.46 (792)
DT2-B4	28	1714 (3775)	0.025 (0.0010)	4.71 (684)	1798 (3960)	4.94 (717)
Average				**4.96 (720)**		**5.01 (740)**
DT4-B1	28	1816 (4000)	0.023 (0.0009)	4.98 (722)	2009 (4425)	5.50 (798)
DT4-B2	28	1952 (4300)	0.025 (0.0010)	5.37 (780)	2011 (4430)	5.54 (804)
DT4-B3	28	1952 (4300)	0.005 (0.0002)	5.30 (769)	1952 (4300)	5.30 (769)
DT4-B4	28	1839 (4050)	0.023 (0.0009)	4.98 (722)	1855 (4085)	5.02 (728)
Average				**5.17 (750)**		**5.34 (775)**
DT6-B1	28	1952 (4300)	0.005 (0.0002)	5.26 (763)	1952 (4300)	5.26 (763)
DT6-B2	28	1975 (4350)	0.023 (0.0009)	5.36 (778)	2032 (4475)	5.51 (800)
Average				**5.31 (770)**		**5.37 (780)**
DT7-B1	28	*				
DT7-B2	28	1657 (3650)	0.023 (0.0009)	4.60 (667)	1668 (3675)	4.62 (671)

* The gage moved due to impact of failure.

Table A5: ASTM Toughness Indices and Residual Strength Factors for Trial Mixes

Specimen #	First Crack Toughness Nm (inch-lbs)	Toughness Indices I5	I10	I20	Toughness Ratios I10/I5	I20/I10	R5,10	R10,20
DT2-B1	0.04 (0.38)	5.00	9.89	19.35	1.98	1.96	97.8	94.6
DT2-B2	0.30 (2.69)	3.98	7.29	12.53	1.83	1.72	66.2	52.4
DT2-B3	0.22 (1.99)	3.59	6.44	10.84	1.80	1.68	57.0	44.0
DT2-B4	0.23 (2.01)	4.82	9.24	16.84	1.92	1.82	88.4	76.6
Average	**0.20 (1.77)**	**4.35**	**8.22**	**14.89**	**1.88**	**1.80**	**77.4**	**66.8**
DT4-B1	0.23 (2.00)	4.84	9.27	16.83	1.91	1.82	88.6	75.6
DT4-B2	0.29 (2.56)	4.02	6.28	8.49	1.56	1.35	45.2	22.7
DT4-B3	0.07 (0.64)	3.68	6.94	13.19	1.89	1.90	65.2	62.4
DT4-B4	0.28 (2.44)	3.92	7.29	13.09	1.86	1.79	67.4	58.0
Average	**0.22 (1.91)**	**4.12**	**7.45**	**12.90**	**1.81**	**1.72**	**66.7**	**54.7**
DT6-B1	0.07 (0.64)	3.65	6.85	12.87	1.88	1.88	64	60.2
DT6-B2	0.30 (2.66)	3.92	7.23	12.71	1.84	1.76	66.2	54.8
Average	**0.19 (1.65)**	**3.79**	**7.04**	**12.79**	**1.86**	**1.82**	**65.1**	**57.5**
DT7-B1	-	-	-	-	-	-	-	-
DT7-B2	0.24 (2.12)	4.01	7.40	12.97	1.85	1.75	67.8	55.7

Table A6: Japanese Standard - Toughness & Equivalent Flexural Strength for Trial Mixes

Specimen #	Age (Days)	Toughness Nm (Inch-lbs)	Equivalent Flexural Strength MPa (psi)
DT2-B1	28	22.26 (197)	3.10 (450)
DT2-B2	28	14.12 (125)	1.93 (280)
DT2-B3	28	17.18 (152)	2.31 (335)
DT2-B4	28	19.78 (175)	2.73 (396)
Average		**18.44 (162)**	**2.52 (365)**
DT4-B1	28	23.96 (212)	3.30 (479)
DT4-B2	28	11.53 (102)	1.59 (231)
DT4-B3	28	15.59 (138)	2.12 (308)
DT4-B4	28	19.44 (172)	2.64 (383)
Average		**17.63 (156)**	**2.42 (351)**
DT6-B1	28	18.19 (161)	2.45 (356)
DT6-B2	28	21.58 (191)	2.94 (426)
Average		**19.88 (176)**	**2.69 (391)**
DT7-B1	28	-	-
DT7-B2	28	21.90 (153)	2.58 (349)

Table B1: Fresh Concrete Properties for Trial Slab

Date of mix: September 6, 1995.

Environmental Condition		Slump			Air Content	
Temp.° C (°F)	Humidity	mm (Inches)			(%)	
		Before adding Fibers	After adding Fibers but before retempering	After adding fibers & after retempering (sample collected after pumping)	Before Adding Fibers	After Adding Fibers & after retempering (sample collected after pumping)
18.3 (65)	40 %	101 (4.00)	19 (0.75)	82 (3.25)	9.8	8.8

Table B2: Hardened Concrete Properties for Trial Slab

Specimen #	Age (days)	Length mm (inches)	Diameter mm (inches)	Unit Weight Kg/m^3 (pcf)	Static Modulus MPa (Psi)	Compressive Strength MPa (psi)
STC-C1	7	307.2 (12.095)	152.3 (5.997)	2212.4 (138.1)	-	23.43 (3400)
STC-C2	7	306.5 (12.065)	152.4 (5.998)	2208.2 (137.8)	-	23.67 (3435)
Average						**23.56 (3420)**
STC-C3	28	306.6 (12.071)	151.6 (5.970)	2244.6 (140.1)	29601 (4.29 x10^6)	31.25 (4535)
STC-C4	28	305.9 (12.043)	152.7 (6.010)	2211.9 (138.1)	29187 4.23 x10^6)	30.97 (4495)
Average						**31.11 (4515)**
STF-C1	7	309.9 (12.200)	152.0 (5.986)	2201.2 (137.4)	-	24.94 (3555)
STF-C2	7	307.3 (12.100)	152.1 (5.987)	2194.2 (137.0)	-	24.22 (3515)
Average						**24.36 (3535)**
STF-C3	28	307.9 (12.122)	152.0 (5.986)	2207.0 (137.8)	29394 (4.26 x10^6)	31.83 (4620)
STF-C4	28	309.0 (12.165)	152.8 (6.015)	2186.1 (136.5)	29187 (4.23 x10^6)	31.14 (4520)
Average						**31.49 (4570)**

Table B3: First Crack Strength and Maximum Flexural Strength for Trial Slab

Specimen #	Age (Days)	First Crack Load kg (lbs)	First Crack Deflection mm (inches)	First Crack Stress MPa (psi)	Maximum Load kg (lbs)	Flexural Strength MPa (psi)
DC-B1	28	-	-	-	1612 (3550)	4.39 (637)
DC-B2	28	-	-	-	1339 (2950)	3.78 (549)
DC-B3	28	-	-	-	1623 (3575)	4.44 (644)
DC-B4	28	-	-	-	1398 (3080)	3.77 (548)
Average						**4.10 (595)**
DF-B1	28	1487 (3275)	0.010 (0.0004)	4.05 (588)	1512 (3330)	4.12 (598)
DF-B2	28	1748 (3850)	0.031 (0.0012)	4.84 (703)	1816 (4000)	5.04 (731)
DF-B3	28	1407 (3100)	0.005 (0.0002)	3.67 (533)	1407 (3100)	3.67 (533)
DF-B4	28	1589 (3500)	0.023 (0.0009)	4.14 (601)	1673 (3685)	4.36 (633)
DF-B5	28	1623 (3575)	0.020 (0.0008)	4.36 (633)	1684 (3710)	4.52 (657)
Average				**4.20 (610)**		**4.34 (630)**

Table B4: ASTM Toughness Indices and Residual Strength Factors for Trial Slab

Specimen #	First Crack Toughness Nm (inch-lbs)	Toughness Indices I5	I10	I20	Toughness Ratios I10/I5	I20/I10	R5,10	R10,20
DF-B1	0.11 (0.95)	3.75	7.05	13.15	1.88	1.87	66.0	61.0
DF-B2	0.30 (2.61)	4.56	8.68	15.79	1.90	1.82	82.4	71.1
DF-B3	0.05 (0.46)	3.65	6.88	13.05	1.88	1.90	64.6	61.7
DF-B4	0.20 (1.77)	4.64	8.86	16.21	1.91	1.83	84.4	73.5
DF-B5	0.25 (2.23)	3.61	6.70	12.32	1.86	1.84	61.8	56.2
Average	**0.18 (1.60)**	**4.04**	**7.63**	**14.10**	**1.89**	**1.85**	**71.8**	**56.2**

Table B5: Japanese Standard - Toughness & Equivalent Flexural Strength for Trial Slab

Specimen #	Age (Days)	Toughness Nm (Inch-lbs)	Equivalent Flexural Strength MPa (psi)
DF-B1	28	27.01 (239)	3.69 (536)
DF-B2	28	28.48 (252)	3.97 (576)
DF-B3	28	25.09 (222)	3.29 (478)
DF-B4	28	21.70 (192)	2.83 (411)
DF-B5	28	17.51 (155)	2.36 (342)
Average		**23.95 (212)**	**3.22 (467)**

Table C1: Mixture Proportion for additional Trial Mixes

Mixture Designation & Date of Casting	W/C	W/(C+F)	Mixture Proportions Kg/m^3 (lbs/cubic yard)					Fiber Dosage	AEA
			Cement	Coarse Aggregate	Fine Aggregate	Fly Ash	Water	Kg/m^3 (lbs/cu.yd)	mL/m^3 oz/cu.yd
DT-8 09/08/95	0.54	0.44	338.0 (570)	877.6 (1480)	711.6 (1200)	74.1 (125)	183.8 (310)	14.8 (25) (1.67%)	464 (12.0)
DT-9 09/08/95	0.61	0.50	338.0 (570)	877.6 (1480)	711.6 (1200)	74.1 (125)	207.6 (350)	14.8 (25) (1.67%)	496 (12.8)
DT-10 09/08/95	0.54	0.44	338.0 (570)	794.6 (1340)	794.6 (1340)	74.1 (125)	183.8 (310)	14.8 (25) (1.67%)	496 (12.8)

Fiber description: 50mm (2 inches) long 63mm (25 mil) straight polyolefin fibers

Table C2: Fresh Concrete Properties for additional Trial Mixes

Mixture #	Room Temp.	Room Humidity	Concrete Temp.	Unit Weight	Air Content	Slump mm (inches)	
	°C (°F)	(%)	°C (°F)	Kg/m^3 (pcf)	(%)	Before Retemper	After Retemper
DT-8	21.1 (70)	25	26.4 (79.6)	2402.3 (150.0)	4.4	70 (2.75)	70 (2.75)
DT-9	23.9 (75)	30	26.3 (79.3)	2356.0 (147.1)	7.4	152 (6.00)	-
DT-10	23.9 (75)	30	23.8 (74.9)	2375.9 (148.3)	5.4	76 (3.00)	152 (6.00)

NOTE: For mix DT-8, after measuring the slump, 30 cc of Superplasticizer (WRDA-19) was added and mixed for 2 minutes. The slump was again taken after about 6 minutes. The slump was the same. For mix DT-10, after measuring the slump, 65 cc of superplasticizer (WRDA-19) was added and mixed for 2 minutes. The slump was taken after about 5 minutes after adding the superplasticizer. The slump had doubled to 6 inches.

Table C3: Hardened Concrete Properties for additional Trial Mixes

Specimen #	Age (days)	Length mm (inches)	Diameter mm (inches)	Unit Weight Kg/m^3 (pcf)	Static Modulus MPa (Psi)	Compressive Strength MPa (psi)
DT8-C1	7	309.2 (12.175)	151.8 (5.975)	2327.1 (145.3)	-	30.21 (4385)
DT8-C2	7	309.3 (12.175)	152.7 (6.010)	2308.0 (144.1)	-	29.52 (4285)
Average						**29.87 (4335)**
DT9-C1	7	306.3 (12.060)	152.0 (5.985)	2211.2 (138.1)	-	20.81 (3020)
DT9-C2	7	308.1 (12.130)	152.2 (5.990)	2202.6 (137.5)	-	20.05 (2910)
Average						**20.43 (2965)**
DT10-C1	7	306.1 (12.050)	151.9 (5.980)	2314.3 (144.5)	-	28.46 (4130)
DT10-C2	7	308.1 (12.130)	151.8 (5.975)	2319.4 (144.8)	-	28.45 (4100)
Average						**28.35 (4115)**
DT8-C3	28	309.4 (12.182)	152.2 (5.990)	2306.1 (144.0)	36708 (5.32×10^6)	41.36 (5995)
DT8-C4	28	307.3 (12.100)	152.2 (5.990)	2321.7 (145.0)	36708 (5.32×10^6)	41.44 (6015)
Average						**41.37 (6005)**
DT9-C3	28	308.0 (12.124)	152.0 (5.985)	2183.3 (136.3)	24495 (3.55×10^6)	29.87 (4335)
DT9-C4	28	306.7 (12.075)	152.0 (5.986)	2191.4 (136.8)	24495 3.55×10^6)	30.35 (4405)
Average						**30.11 (4370)**
DT10-C3	28	309.1 (12.170)	152.1 (5.989)	2317.3 (144.7)	36708 (5.32×10^6)	41.10 (5965)
DT10-C4	28	305.7 (12.034)	151.9 (5.980)	2309.2 (144.2)	36708 (5.32×10^6)	40.48 (5875)
Average						**40.79 (5920)**

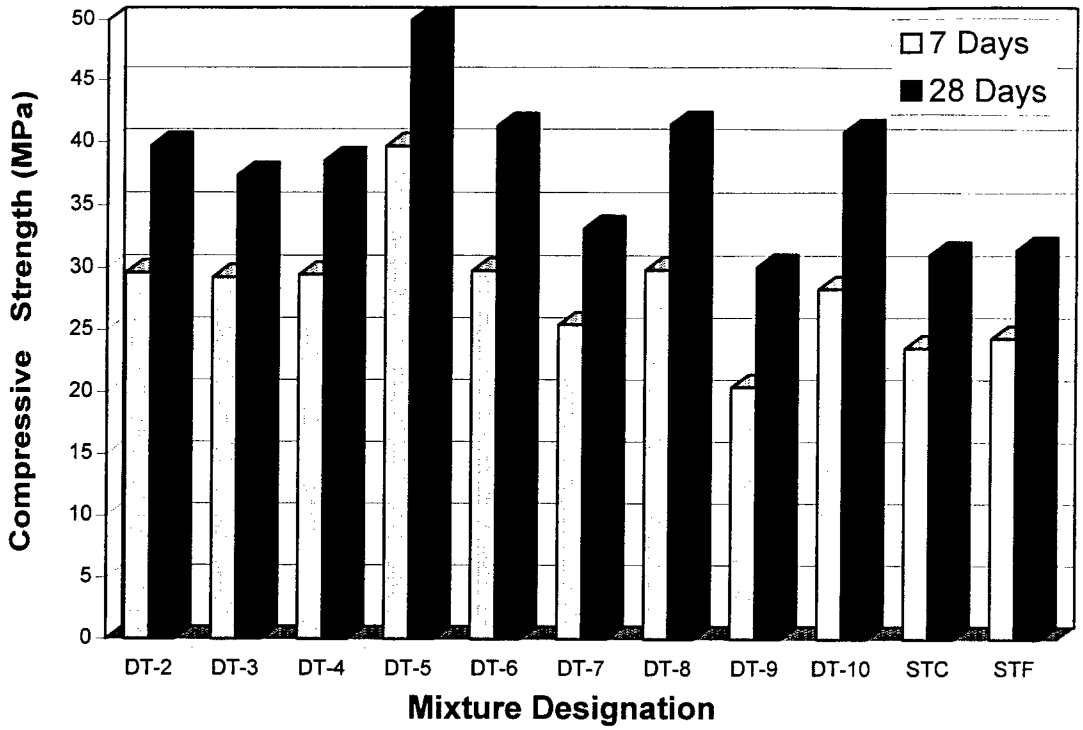


Fig A1: Comparison of Compressive Strength for trial mixes

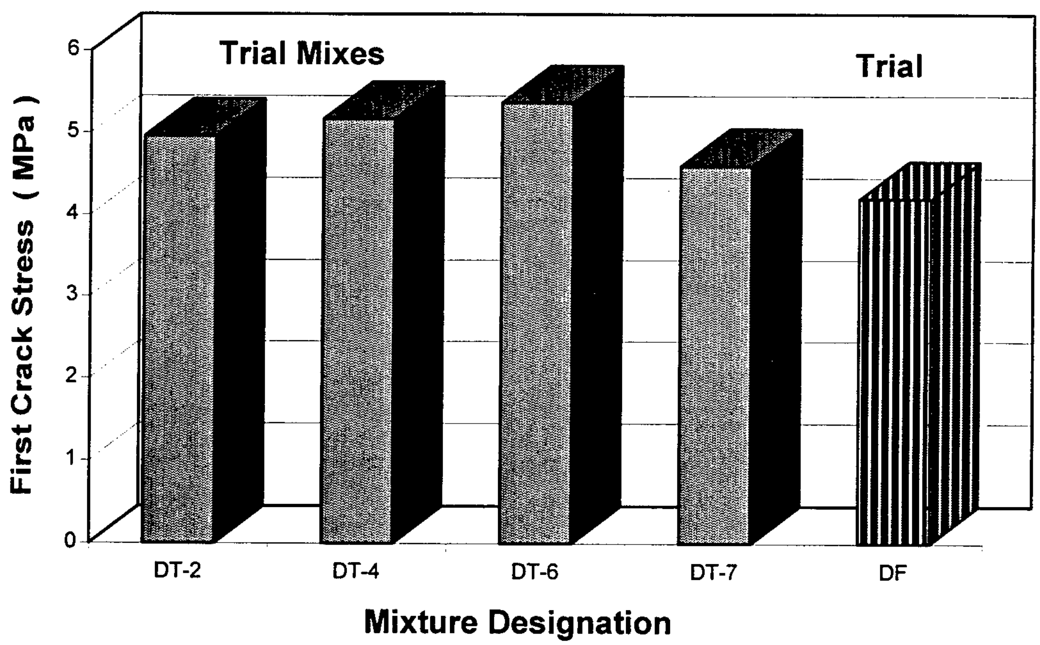


Fig A2: Comparison of First Crack Stress for trial mixes

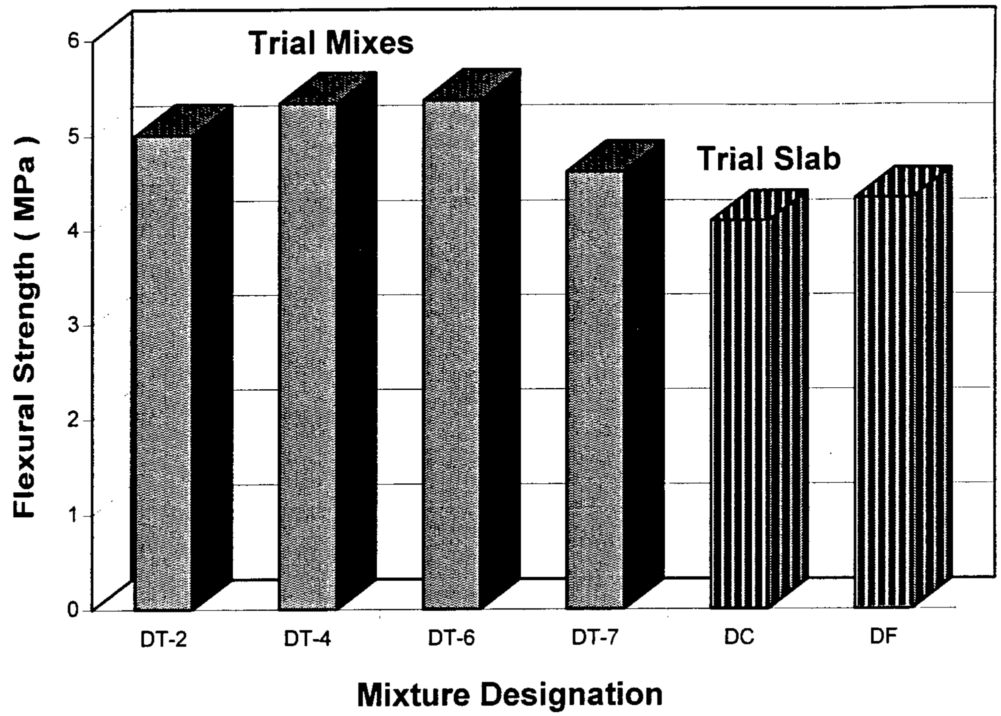


Fig A3: Comparison of Flexural Strength for trial mixes

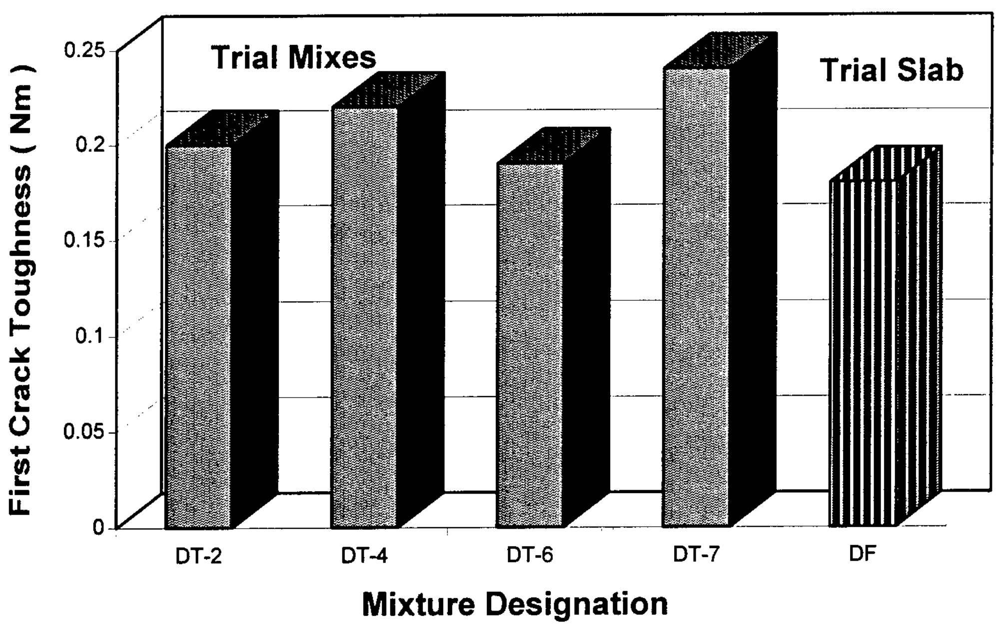


Fig A4: Comparison of ASTM First Crack Toughness for trial mixes

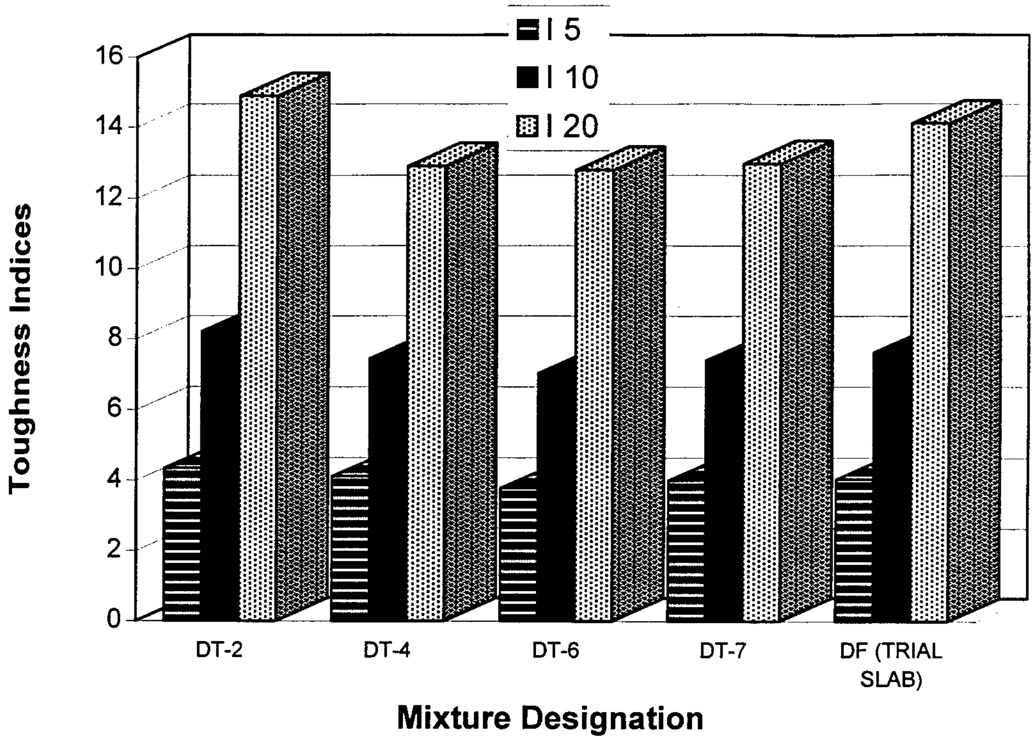


Fig A5: Comparison of ASTM Toughness Indices for trial mixes

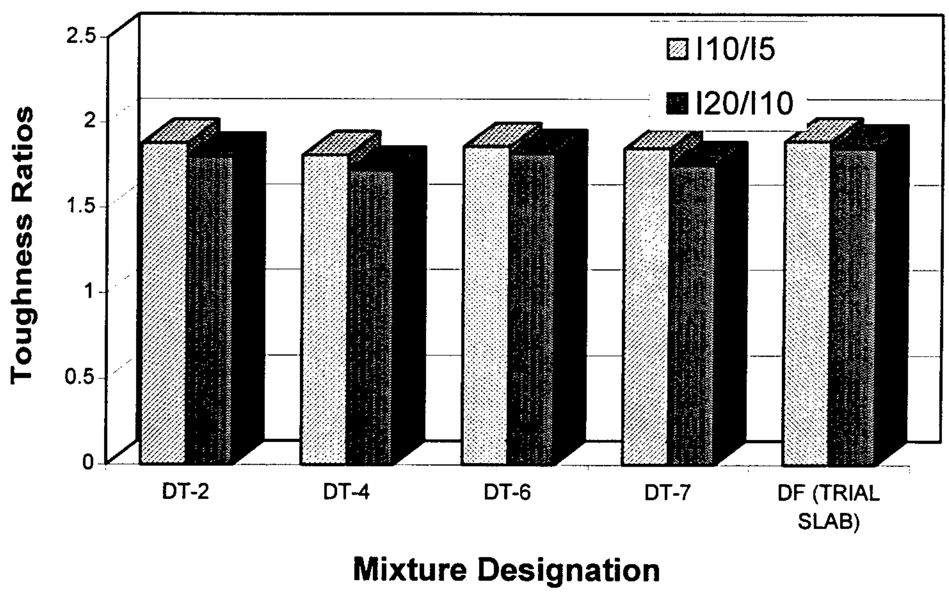


Fig A6: Comparison of ASTM Toughness Ratios for trial mixes

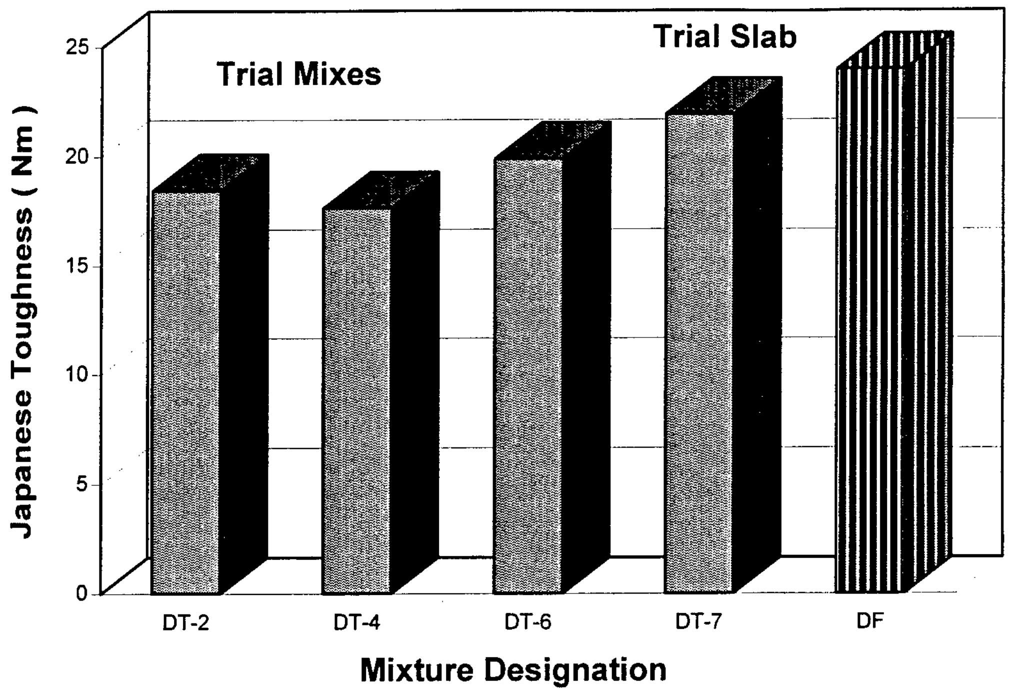


Fig A7: Comparison of Japanese Toughness for trial mixes

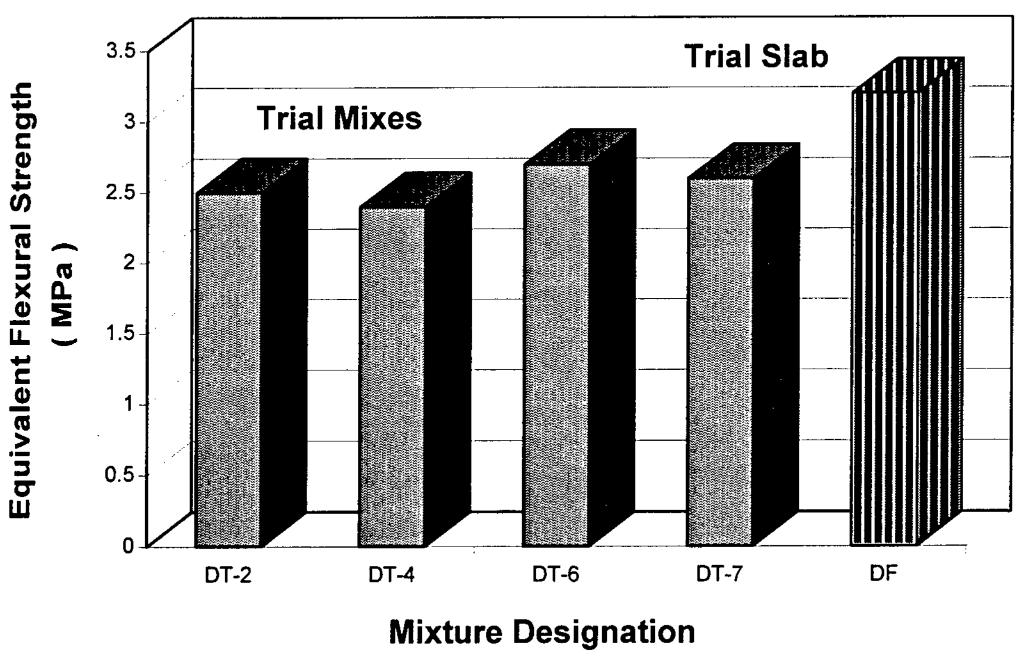


Fig A8: Comparison of Japanese Standard Equivalent Flexural Strength for trial mixes

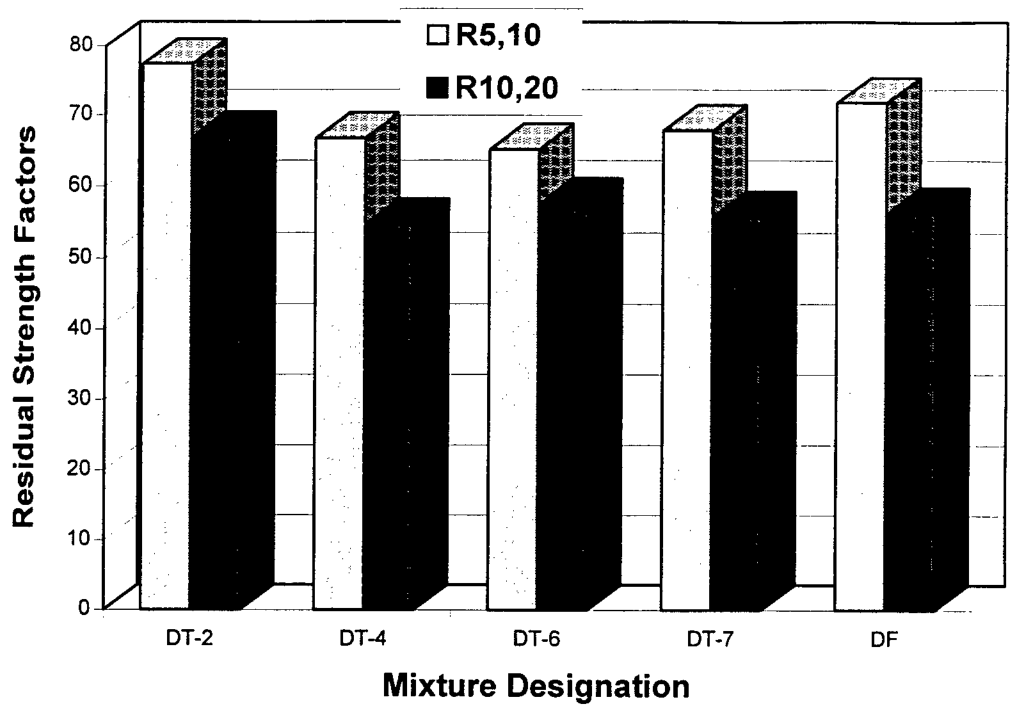


Fig A9: Comparison of Residual Strength Factors for trial mixes

APPENDIX – B

Details of the Mixtures used in the Construction of Bridge-Deck Slab and Barrier

Mix Designation	Description
SFBD	Concrete used for Bridge-Deck
SFBAR	Concrete used for Barrier

Table D1: Fresh Concrete Properties for Bridge-Deck

Test # & Date of Mix	Environmental Conditions Temp.	Humidity	Concrete Temp.	Unit Weight	Air Content	Slump	Actual Fiber Content
	°C (°F)	(%)	°C (°F)	Kg/m³ (lb/cu ft)	(%)	mm (inches)	Kg/m³ (lb/cu. yd)
SFDB1 09/22/95	10.0 (50)	30	14.1 (57.3)	-	3.8	45 (1.75)	
SFBD1 09/22/95	29.4 (85)	15	16.9 (62.5)	2362.9 (147.5)	5.0	64 (2.50)	14.9 (25.2)
SFBD1 09/22/95	29.4 (85)	05	19.9 (67.9)	-	4.7	70 (2.75)	
SFBD2 09/26/95	10.0 (50)	35	17.1 (62.8)	-	5.5	108 (4.25)	15.1 (25.4)
SFBD2 09/26/95	29.4 (85)	10	18.8 (65.8)	-	6.8	108 (4.25)	-

Table D2: Number of Specimens for Bridge-Deck

Mixture Designation	Number of Specimens Beams	Cylinders	Impact
SFBD 1	6	6	8
SFBD 2	7	6	8

Table D3: Hardened Concrete Properties for Bridge-Deck

Specimen #	Age (days)	Length mm (inches)	Dia. mm (inches)	Unit Wt Kg/m^3 (pcf)	Static Modulus Mpa (Psi)	Compressive Strength MPa (psi)
SFBD1-C1	7	309.9 (12.200)	151.9 (5.982)	2316.9 (144.6)	29463 (4.27 x10^6)	31.14 (4520)
SFBD1-C2	7	308.1 (12.130)	151.8 (5.975)	2311.4 (144.3)	29532 (4.28 x10^6)	30.45 (4420)
SFBD1-C3	7	310.1 (12.210)	152.2 (5.991)	2292.0 (143.1)	29394 (4.26 x10^6)	30.80 (4470)
Average				**2306.8 (144.0)**		**30.80 (4470)**
SFBD1-C4	28	311.5 (12.262)	151.9 (5.982)	2305.2 (143.9)	29463 (4.27 x10^6)	40.44 (5870)
SFBD1-C5	28	308.5 (12.145)	151.6 (5.968)	2305.7 (143.9)	29601 (4.29 x10^6)	39.89 (5790)
SFBD1-C6	28	312.2 (12.290)	152.2 (5.990)	2285.9 (142.7)	29394 (4.26 x10^6)	40.10 (5820)
Average				**2298.9 (143.5)**		**40.13 (5825)**
SFBD2-C1	7	309.9 (12.200)	152.0 (5.984)	2259.2 (141.0)	29463 (4.27 x10^6)	25.35 (3680)
SFBD2-C2	7	307.8 (12.117)	152.3 (5.995)	2273.9 (142.0)	29325 (4.25)	25.87 (3755)
SFBD2-C3	7	310.1 (12.208)	152.0 (5.985)	2265.0 (141.4)	29463 (4.27 x10^6)	25.73 (3735)
Average				**2266.0 (141.5)**		**25.66 (3725)**
SFBD2-C4	28	308.4 (12.141)	152.0 (5.986)	2276.4 (142.1)	29394 (4.26 x10^6)	36.48 (5295)
SFBD2-C5	28	309.8 (12.195)	152.0 (5.986)	2266.4 (141.5)	29394 (4.26 x10^6)	36.72 (5330)
SFBD2-C6	28	311.0 (12.242)	152.0 (5.985)	2274.5 (142.0)	29463 (4.27 x10^6)	37.10 (5385)
Average				**2272.4 (141.9)**		**36.76 (5335)**

Table D4: First Crack Strength and Maximum Flexural Strength for Bridge-Deck

Specimen #	Age (Days)	First Crack Load Kg (lbs)	First Crack Deflection mm (inches)	First Crack Stress MPa (psi)	Maximum Load Kg (lbs)	Flexural Strength MPa (psi)
SFBD1-B1	7	1861 (4100)	0.018 (0.0007)	5.26 (764)	1889 (4160)	5.34 (775)
SFBD1-B2	7	1616 (3560)	0.005 (0.0002)	4.28 (622)	1616 (3560)	4.29 (622)
Average				**4.79 (695)**		**4.82 (700)**
SFBD1-B3	28	2251 (4960)	0.152 (0.0006)	6.34 (920)	2368 (5215)	6.66 (967)
SFBD1-B4	28	2031 (4475)	0.025 (0.0010)	5.72 (830)	2066 (4550)	5.81 (844)
SFBD1-B5	28	1986 (4375)	0.025 (0.0010)	5.64 (819)	1986 (4375)	5.64 (819)
SFBD1-B6	28	2134 (4700)	0.025 (0.0010)	5.69 (826)	2304 (5075)	6.15 (892)
Average				**5.86 (850)**		**6.06 (880)**
SFBD2-B1	7	1639 (3610)	0.020 (0.0008)	4.49 (652)	1675 (3690)	4.59 (677)
SFBD2-B2	7	1600 (3525)	0.005 (0.0002)	4.09 (594)	1600 (3525)	4.09 (594)
SFBD2-B3	7	1385 (3050)	0.023 (0.0009)	4.00 (581)	1426 (3140)	4.12 (598)
Average				**4.20 (610)**		**4.27 (620)**
SFBD2-B4	28	1930 (4250)	0.018 (0.0007)	5.34 (776)	1936 (4265)	5.36 (779)
SFBD2-B5	28	1943 (4280)	0.018 (0.0007)	5.10 (741)	1943 (4280)	5.10 (741)
SFBD2-B6	28	2179 (4800)	0.025 (0.0010)	6.00 (871)	2179 (4800)	6.00 (871)
SFBD2-B7	28	2238 (4930)	0.013 (0.0005)	5.81 (844)	2238 (4930)	5.81 (844)
Average				**5.58 (810)**		**5.58 (810)**

Table D5: ASTM Toughness Indices and Residual Strength Factors for Bridge-Deck

Specimen #	First Crack Toughness Nm (inch-lbs)	Toughness Indices I5	I10	I20	Toughness Ratios I10/I5	I20/I10	R5,10	R10,20
SFBD1-B1	0.19 (1.68)	4.40	8.43	15.79	1.92	1.87	80.6	73.6
SFBD1-B2	0.04 (0.36)	4.94	9.74	18.96	1.97	1.95	96.0	92.2
Average	**0.12 (1.02)**	**4.67**	**9.09**	**17.38**	**1.94**	**1.91**	**88.3**	**82.9**
SFBD1-B3	0.27 (2.41)	4.14	7.50	13.25	1.81	1.77	67.2	57.5
SFBD1-B4	0.28 (2.50)	4.53	8.60	15.56	1.90	1.81	81.4	69.6
SFBD1-B5	0.31 (2.71)	4.04	7.30	12.08	1.81	1.65	65.2	47.8
SFBD1-B6	0.28 (2.51)	4.93	9.55	17.71	1.94	1.85	92.4	81.6
Average	**0.29 (2.53)**	**4.41**	**8.24**	**14.65**	**1.86**	**1.77**	**76.5**	**64.1**
SFBD2-B1	0.23 (2.02)	3.86	7.27	13.47	1.88	1.85	68.2	62.0
SFBD2-B2	0.04 (0.35)	5.02	9.92	19.24	1.97	1.94	98.0	93.2
SFBD2-B3	0.19 (1.69)	4.26	8.07	14.85	1.90	1.84	76.2	67.8
Average	**0.15 (1.35)**	**4.38**	**8.42**	**15.85**	**1.92**	**1.88**	**80.8**	**74.3**
SFBD2-B4	0.22 (1.90)	4.04	7.48	13.20	1.85	1.76	68.8	57.2
SFBD2-B5	0.21 (1.81)	4.24	8.09	15.10	1.91	1.87	76.6	70.1
SFBD2-B6	0.37 (3.30)	3.38	6.27	11.12	1.85	1.77	57.8	48.5
SFBD2-B7	0.14 (1.23)	4.89	9.41	17.34	1.93	1.84	90.4	79.3
Average	**0.23 (2.06)**	**4.14**	**7.81**	**14.19**	**1.88**	**1.81**	**73.4**	**63.8**

Table D6: Japanese Standard -Toughness & Equivalent Flexural Strength for Bridge-Deck

Specimen #	Age (Days)	Toughness Nm (Inch-lbs)	Equivalent Flexural Strength MPa (psi)
SFBD1-B1	7	22.83 (202)	3.23 (469)
SFBD1-B2	7	15.82 (140)	2.11 (307)
Average		**19.32 (171)**	**2.67 (388)**
SFBD1-B3	28	18.42 (163)	2.60 (378)
SFBD1-B4	28	18.53 (164)	2.62 (380)
SFBD1-B5	28	15.70 (139)	2.24 (325)
SFBD1-B6	28	24.29 (215)	3.26 (473)
Average		**19.32 (171)**	**2.68 (389)**
SFBD2-B1	7	17.74 (157)	2.44 (354)
SFBD2-B2	7	23.05 (204)	2.96 (429)
SFBD2-B3	7	16.05 (142)	2.33 (338)
Average		**18.98 (168)**	**2.58 (374)**
SFBD2-B4	28	15.59 (138)	2.16 (314)
SFBD2-B5	28	23.50 (208)	3.10 (450)
SFBD2-B6	28	16.49 (146)	2.29 (332)
SFBD2-B7	28	20.79 (184)	2.70 (393)
Average		**19.10 (169)**	**2.56 (372)**

Table D7: Impact Test Results for Bridge-Deck

Specimen #	Number of Blows	
	First Crack	Failure
SFBD1 I-1	145	634
SFBD1 I-2	35	362
SFBD1 I-3	21	351
SFBD1 I-4	100	388
SFBD1 I-5	55	565
SFBD1 I-6	90	570
SFBD1 I-7	22	420
SFBD1 I-8	109	720
SFBD2 I-1	35	850
SFBD2 I-2	250	600
SFBD2 I-3	60	870
SFBD2 I-4	20	381
SFBD2 I-5	26	342
SFBD2 I-6	54	410
SFBD2 I-7	170	320
SFBD2 I-8	120	480
Average	**82**	**516**

Table E1: Properties of Fresh Concrete for Barrier

Mixture Designation & Date of Mix	Environmental Conditions Temp.	Humidity	Concrete Temp.	Unit Weight	Air Content	Slump
	°C (°F)	(%)	°C (°F)	kg/m^3 (pcf)	(%)	mm (inches)
SFBAR-1 10/26/95	10 (50)	60	14 (57.2)	-	7.0	54 (2.125)

Table E2: Number of Specimens for Barrier

Mixture Designation	Number of Specimens Beams	Cylinders
SFBAR	4	3

Table E3: Hardened Concrete Properties for Barrier

Specimen #	Age (days)	Length mm (inches)	Dia. mm (inches)	Unit Weight kg/m^3 (pcf)	Static Modulus MPa (Psi)	Compressive Strength MPa (psi)
SFBAR-C1	28	310.0 (12.196)	152.3 (5.995)	2235.0 (139.5)	29325 (4.25×10^6)	34.17 (4960)
SFBAR-C2	28	311.0 (12.244)	152.3 (5.995)	2250.0 (140.5)	36639 (5.13×10^6)	32.93 (4780)
SFBAR-C3	28	312.0 (12.250)	152.3 (5.995)	2257.0 (140.9)	29325 (4.25×10^6)	34.79 (5050)
Average				**2248.0 (140.3)**		**33.97 (4930)**

Table E4: First Crack Strength and Maximum Flexural Strength for Barrier

Specimen #	Age (Days)	First Crack Load kg (lbs)	First Crack Deflection mm (inches)	First Crack Stress Mpa (psi)	Maximum Load Kg (lbs)	Flexural Strength MPa (psi)
SFBAR-B1	28	1528 (3365)	0.023 (0.0009)	4.22 (613)	1528 (3365)	4.22 (613)
SFBAR-B2	28	1498 (3300)	0.013 (0.0005)	4.19 (608)	1521 (3350)	4.25 (617)
SFBAR-B3	28	1566 (3540)	0.010 (0.0004)	4.17 (605)	1614 (3555)	4.18 (607)
SFBAR-B4	28	1832 (4035)	0.013 (0.0005)	5.04 (731)	1832 (4035)	5.04 (731)
Average				**4.41 (640)**		**4.42 (642)**

Table E5: ASTM Toughness Indices & Residual Strength Factors for Barrier

Specimen #	First Crack Toughness Nm (inch-lbs)	Toughness Indices I5	I10	I20	Toughness Ratios I10/I5	I20/I10	R5,10	R10,20
SFBAR-B1	0.18 (1.58)	4.69	8.94	16.16	1.90	1.81	85.0	72.2
SFBAR-B2	0.16 (1.40)	3.33	6.08	10.96	1.82	1.80	55.0	48.8
SFBAR-B3	0.13 (1.14)	3.46	6.40	11.84	1.85	1.85	58.8	54.4
SFBAR-B4	0.17 (1.54)	3.56	6.63	12.29	1.86	1.85	61.4	56.6
Average	**0.02 (1.42)**	**3.76**	**7.01**	**12.81**	**1.86**	**1.83**	**65.1**	**58.0**

Table E6: Japanese Standard - Toughness & Equivalent Flexural Strength for Barrier

Specimen #	Age (Days)	Toughness Nm (Inch-lbs)	Equivalent Flexural Strength MPa (psi)
SFBAR-B1	28	22.71 (201)	3.14 (456)
SFBAR-B2	28	18.53 (164)	2.61(379)
SFBAR-B3	28	18.42 (163)	2.40 (348)
SFBAR-B4	28	25.54 (226)	3.54 (513)
Average		**21.36 (189)**	**2.92 (424)**

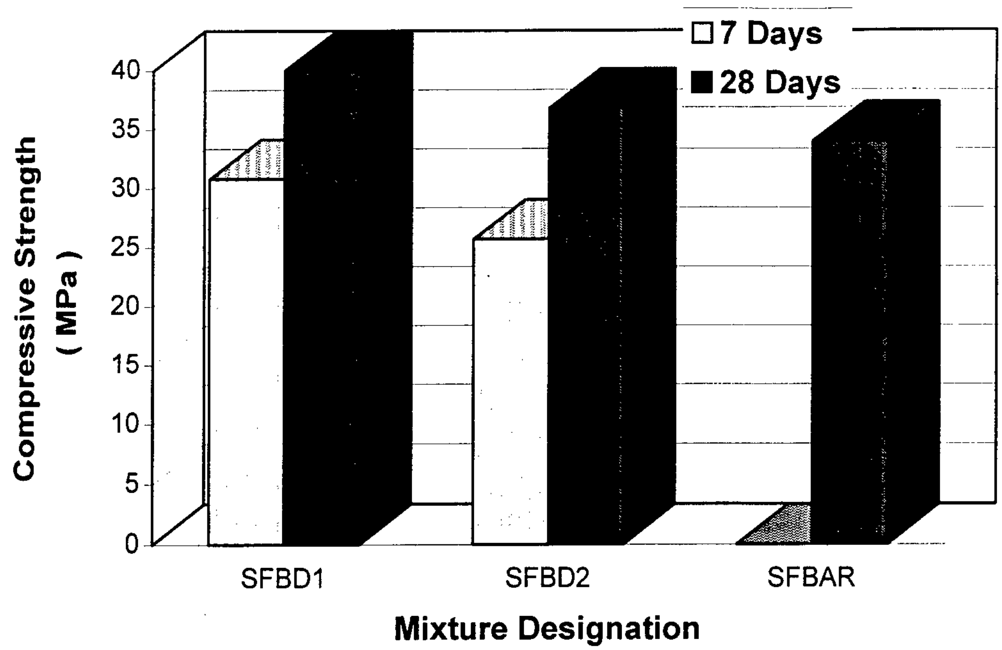


Fig B1: Comparison of Compressive Strength of the mixture used for Construction

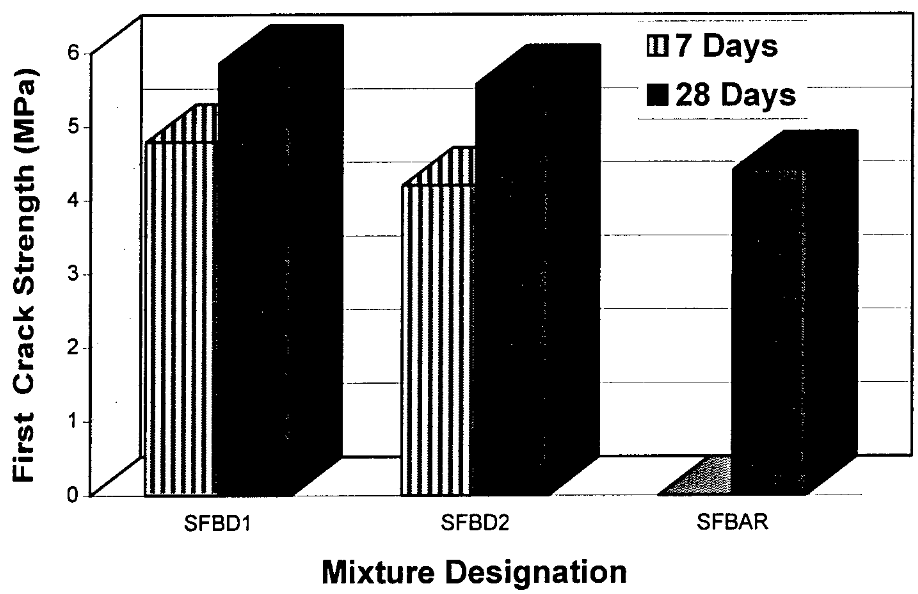


Fig B2: Comparison of First Crack Strength of the mixture used for Construction

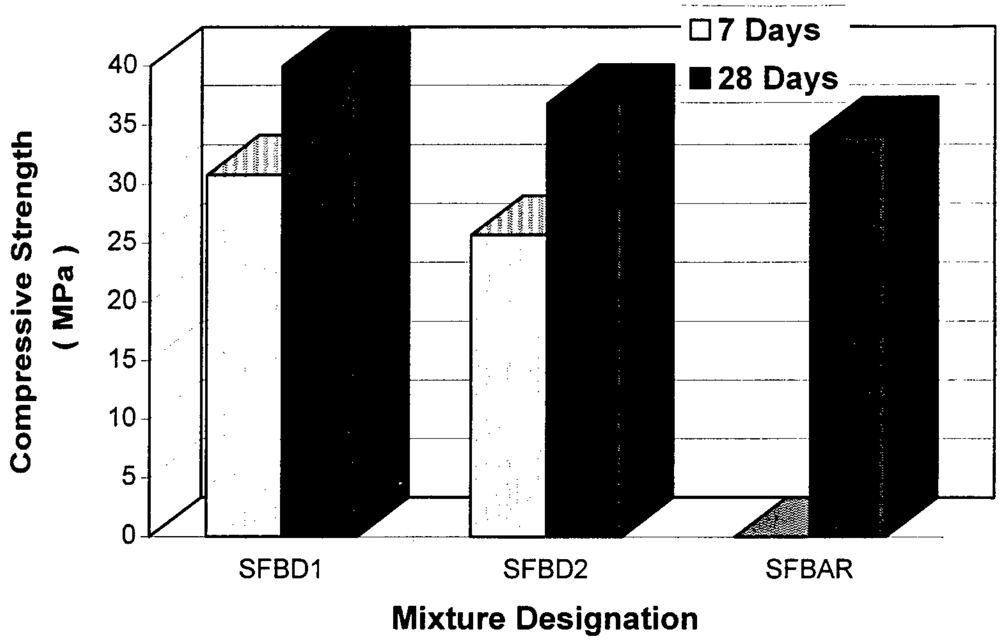


Fig B1: Comparison of Compressive Strength of the mixture used for Construction

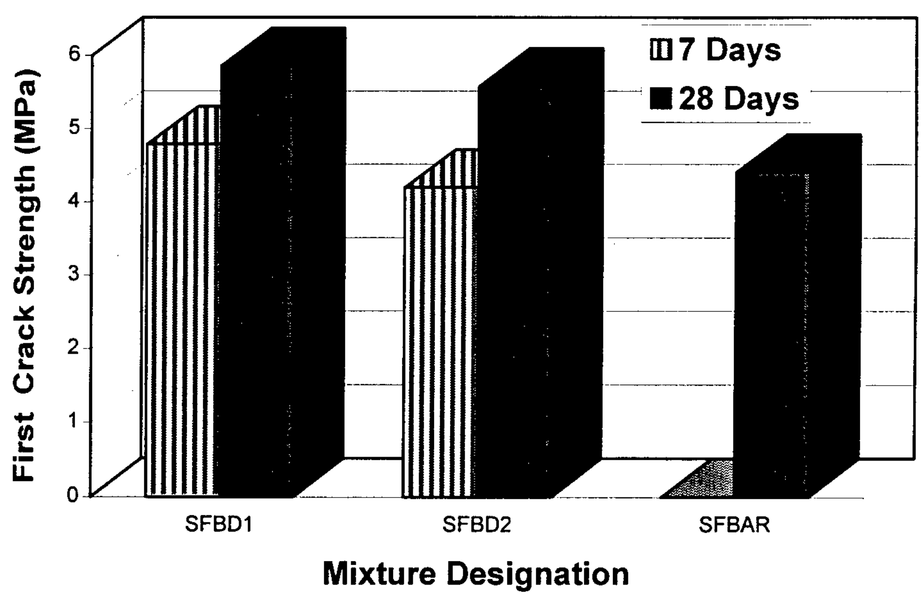


Fig B2: Comparison of First Crack Strength of the mixture used for Construction

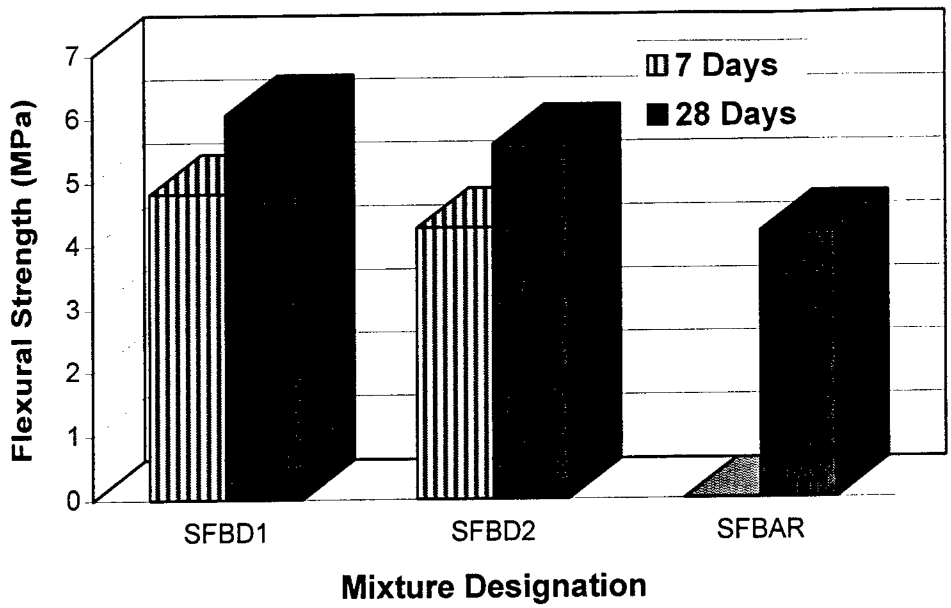


Fig B3: Comparison of Flexural Strength of the mixture used for Construction

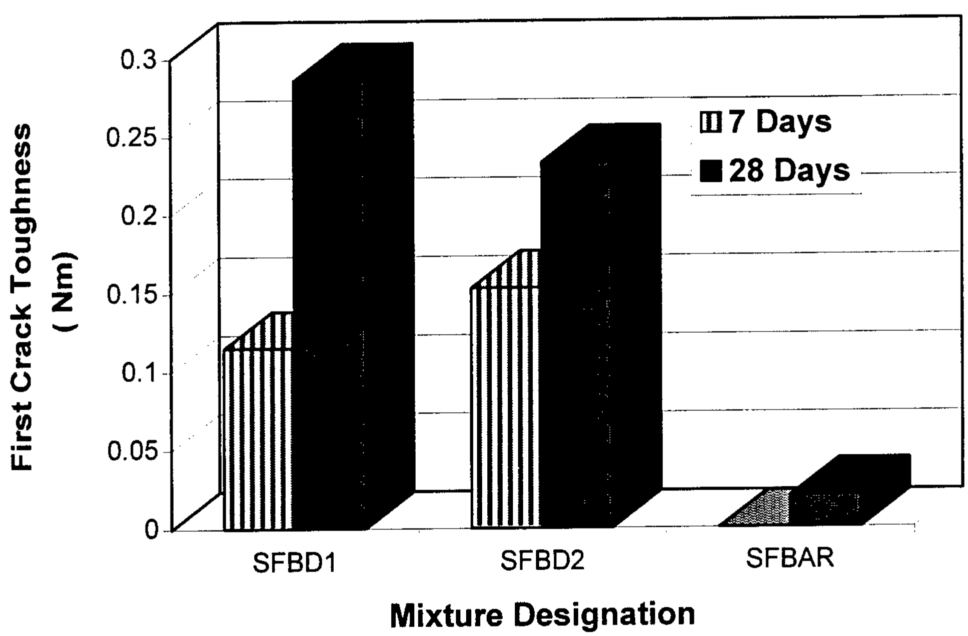


Fig B4: Comparison of First Crack Toughness of the mixture used for Construction

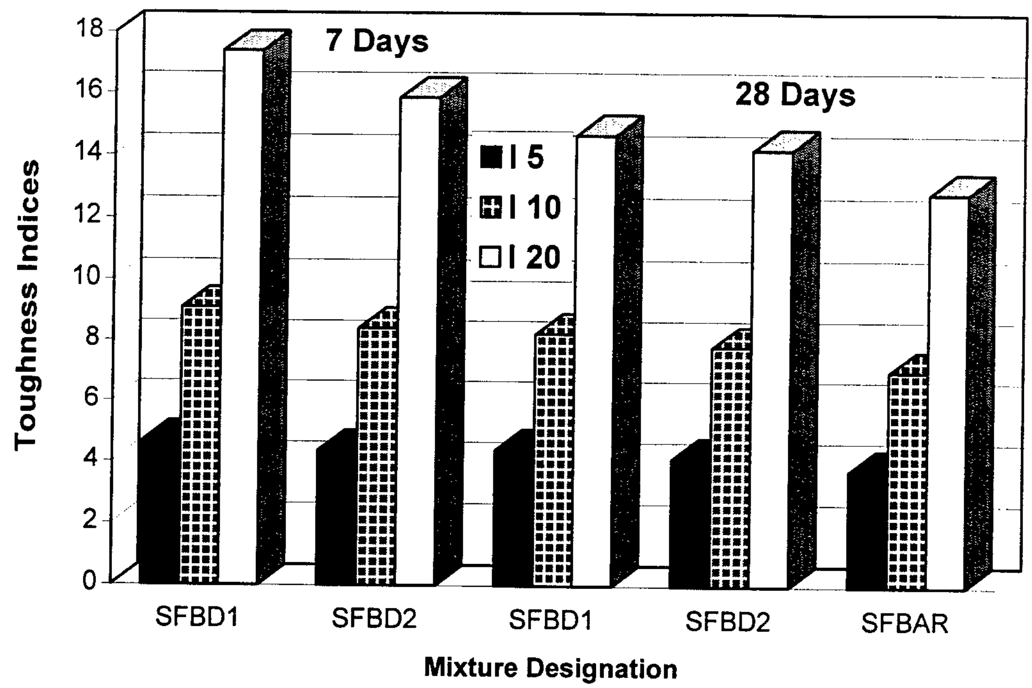


Fig B5: Comparison of ASTM Toughness Indices for the mixture used for Construction

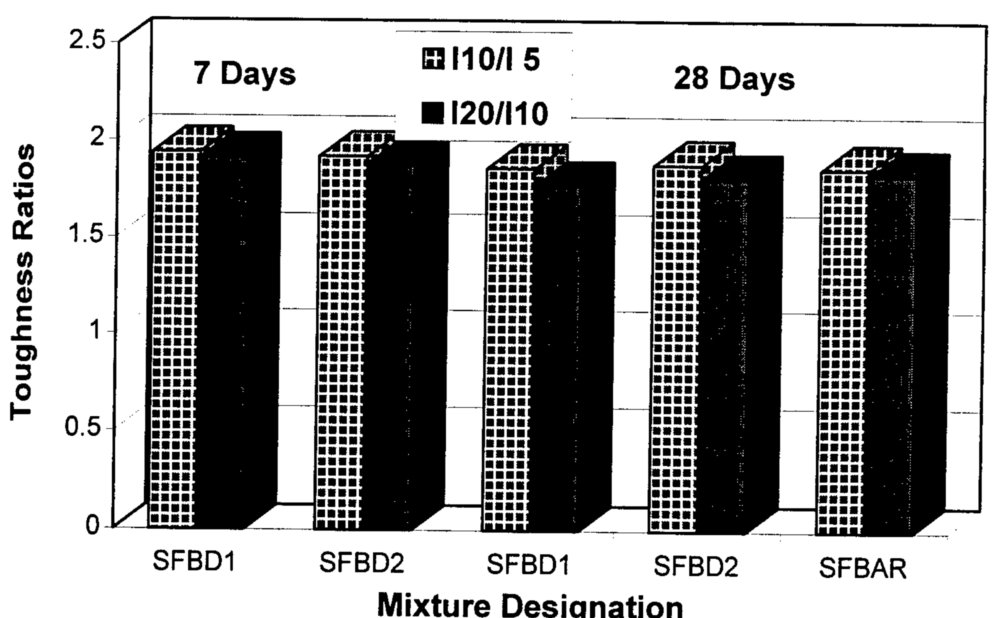


Fig B6: Comparison of ASTM Toughness Ratios of the mixture used for Construction

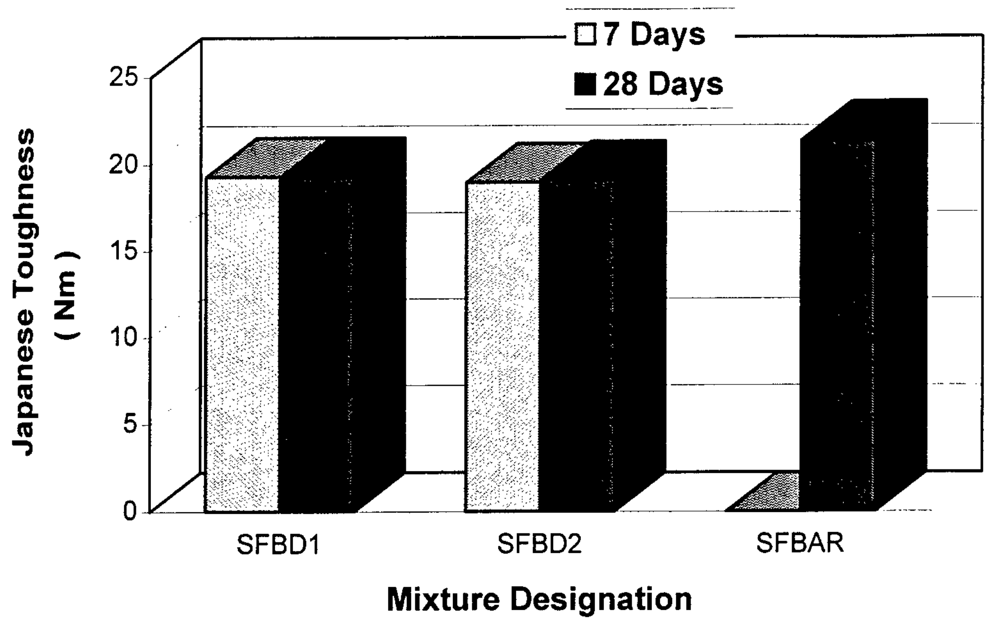


Fig B7: Comparison of Japanese Toughness of the mixture used for Construction

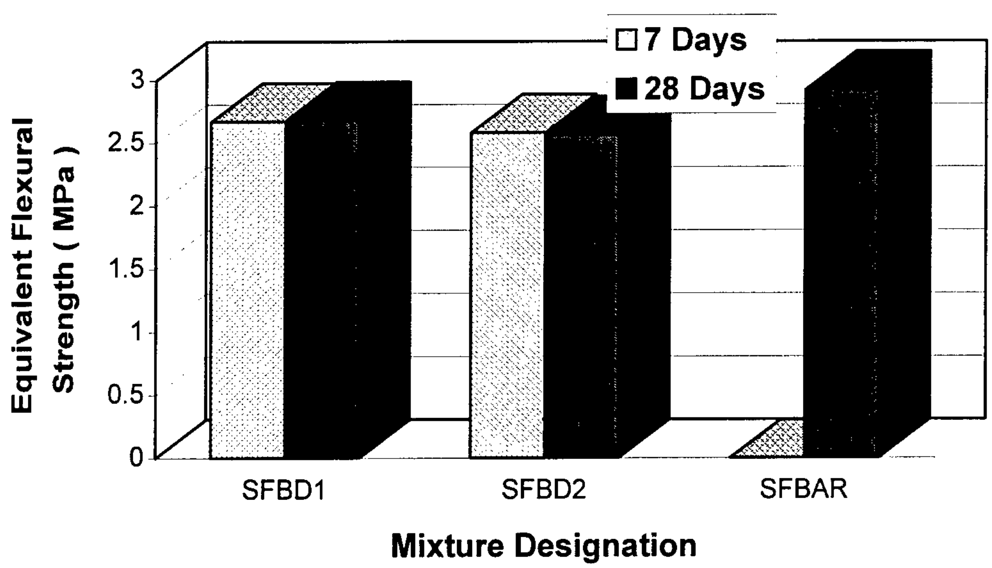


Fig B8: Comparison of Japanese Standard Equivalent Flexural Strength of the mixture used for Construction

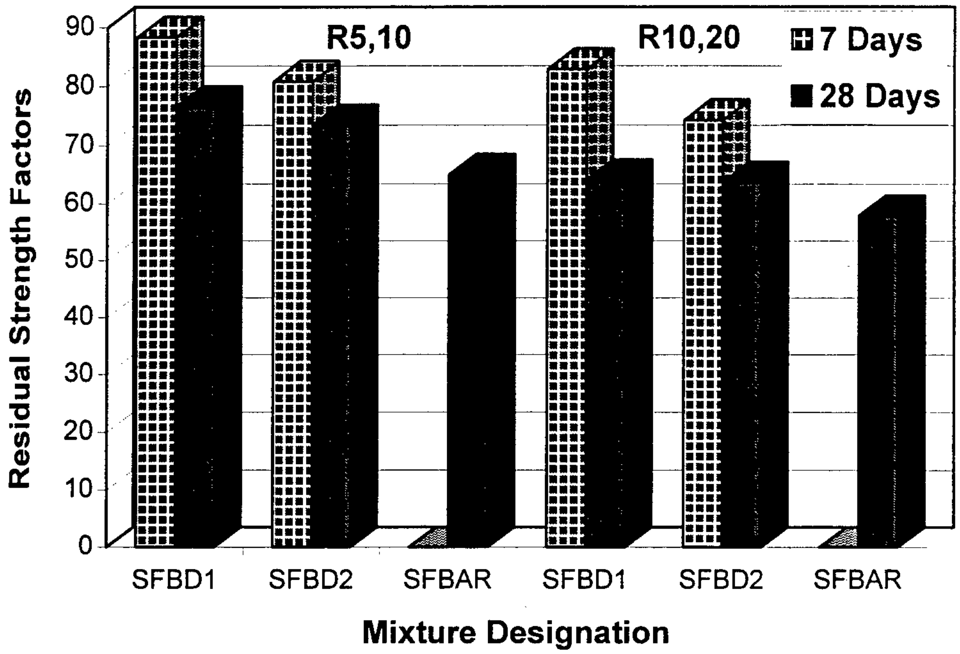


Fig B9: Comparison of Residual Strength Factors of mixture used for Construction

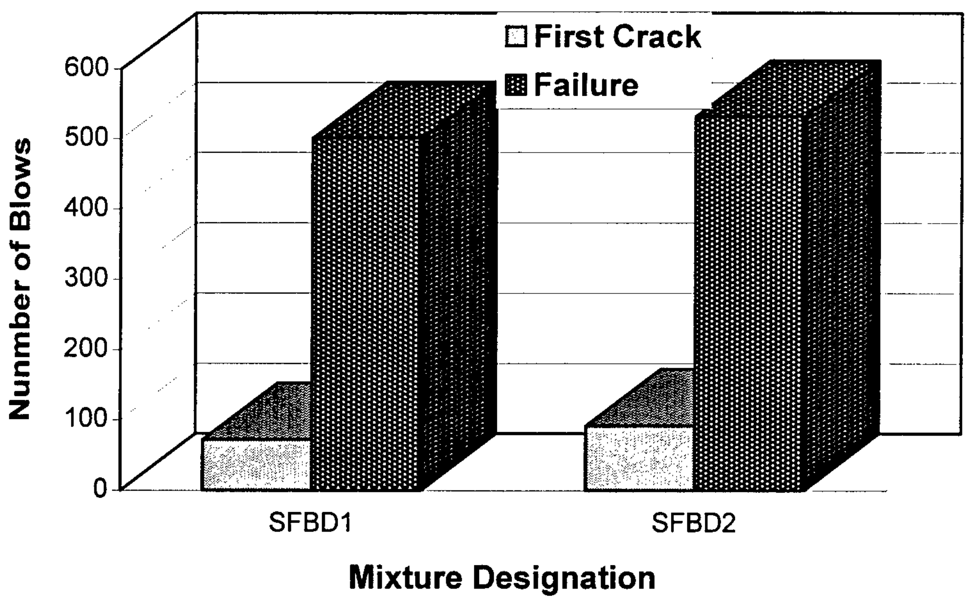


Fig B10: Comparison of Impact Strength of the mixture used for Construction

APPENDIX – C

CRACK DETAILS

Table F1: Cracks Located on the Barriers – East Side

Crack No:	Width of Crack (Survey done on 9 - 8- 96) mm (inch)	Width of Crack (Survey done on 6 - 16- 97) mm (inch)	Status of Crack (With respect to width)	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	< 0.08 (< 0.003)	0.10 (0.004)	Increased	14.74	48.35
2	< 0.08 (< 0.003)	0.10 (0.004)	Increased	17.83	58.50
3	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	18.75	61.50
4	< 0.08 (< 0.003)	0.08 (0.003)	Increased	19.74	64.75
5	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	20.80	68.25
6	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	22.02	72.25
7	< 0.08 (< 0.003)	0.08 (0.003)	Increased	23.24	76.25
8	0.15 (0.006)	0.20 (0.008)	Increased	25.68	84.25
9	0.08 (0.003)	< 0.08 (< 0.003)	Decreased	28.58	93.75
10	0.08 (0.003)	0.10 (0.004)	Increased	30.94	101.50
11	0.10 (0.004)	0.08 (0.003)	Decreased	31.55	103.50
12	0.10 (0.004)	0.10 (0.004)	Same	33.38	109.50
13	0.10 (0.004)	0.15 (0.006)	Increased	35.66	117.00
14	0.10 (0.004)	0.08 (0.003)	Decreased	36.12	118.50
15	0.08 (0.003)	0.08 (0.003)	Same	38.86	127.50
16	0.10 (0.004)	0.08 (0.003)	Decreased	40.54	133.00
17	0.08 (0.003)	0.08 (0.003)	Same	41.61	136.50
18	0.10 (0.004)	0.10 (0.004)	Same	44.35	145.50
19	0.10 (0.004)	0.08 (0.003)	Decreased	46.71	153.25
20	0.10 (0.004)	0.08 (0.003)	Decreased	48.24	158.25
21	0.08 (0.003)	0.08 (0.003)	Same	49.45	162.25
22	0.10 (0.004)	0.08 (0.003)	Decreased	49.99	164.00
23	0.08 (0.003)	0.08 (0.003)	Same	50.67	166.25
24	0.08 (0.003)	0.08 (0.003)	Same	51.74	169.75
25	0.20 (0.008)	0.10 (0.004)	Decreased	60.20	197.50
26	< 0.08 (< 0.003)	0.10 (0.004)	Increased	61.49	201.75
27	0.08 (0.003)	0.10 (0.004)	Increased	62.64	205.50

28	0.15 (0.006)	0.10 (0.004)	Decreased	65.08	213.50
29	0.08 (0.003)	< 0.08 (< 0.003)	Decreased	67.06	220.00
30	0.10 (0.004)	< 0.08 (< 0.003)	Decreased	68.73	225.50
31	0.15 (0.006)	< 0.08 (< 0.003)	Decreased	74.75	245.25
32	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	75.97	249.25
33	0.08 (0.003)	0.08 (0.003)	Same	79.40	260.50
34	0.10 (0.004)	0.08 (0.003)	Decreased	81.53	267.50
35	< 0.08 (< 0.003)	0.10 (0.004)	Increased	81.84	268.50
36	0.15 (0.006)	0.10 (0.004)	Decreased	83.21	273.00
37	0.08 (0.003)	0.08 (0.003)	Same	83.97	275.50
38	< 0.08 (< 0.003)	0.08 (0.003)	Increased	84.74	278.00
39	< 0.08 (< 0.003)	0.10 (0.004)	Increased	87.94	288.50
40		0.10 (0.004)	New Crack	8.66	28.42
41		0.10 (0.004)	New Crack	9.60	31.50
42		0.10 (0.004)	New Crack	16.66	54.67
43		0.10 (0.004)	New Crack	57.86	189.83
44		0.10 (0.004)	New Crack	64.26	210.83
45		0.10 (0.004)	New Crack	66.47	218.08
46		0.10 (0.004)	New Crack	81.03	265.83
47		0.10 (0.004)	New Crack	85.63	280.92

Cracks 40 to 47 are cracks located for the first time on survey done on 6 - 16 - 97. New Cracks of width less than 0.1 mm (0.0039 inch) located on 6 - 16 - 97 have not been tabulated.

Table F1a: Cracks Located on the Barriers - East Side

Crack No:	Width of Crack (Survey done on 6 - 16- 97) mm (inch)	Width of Crack (Survey done on 9 - 6- 97) mm (inch)	Status of Crack (With respect to width)	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	0.10 (0.004)		Same	8.66	28.42
2	0.10 (0.004)		Same	9.60	31.50
3	0.10 (0.004)		Same	14.71	48.25
4	0.10 (0.004)		Same	16.67	54.67
5	0.10 (0.004)		Same	17.84	58.50
6	< 0.08 (< 0.003)		Same	18.75	61.50
7	0.08 (0.003)		Same	19.74	64.75
8	< 0.08 (< 0.003)	0.10 (0.004)	Increased	20.81	68.25
9	< 0.08 (< 0.003)		Same	22.03	72.25
10	0.08 (0.003)	0.10 (0.004)	Increased	23.25	76.25
11	0.20 (0.008)	0.40	Increased	25.69	84.25
12	< 0.08 (< 0.003)	0.10 (0.004)	Increased	28.58	93.75
13	0.10 (0.004)	0.15 (0.006)	Increased	30.95	101.50
14	0.08 (0.003)	0.10 (0.004)	Increased	31.55	103.50
15	0.10 (0.004)	0.20 (0.008)	Increased	33.38	109.50
16	0.15 (0.006)	0.20 (0.008)	Increased	35.67	117.00
17	0.08 (0.003)		Same	36.13	118.50
18	0.08 (0.003)	0.10 (0.004)	Increased	38.87	127.50
19	0.08 (0.003)		Same	40.55	133.00
20	0.08 (0.003)		Same	41.62	136.50
21	0.10 (0.004)	0.25	Increased	44.36	145.50
22	0.08 (0.003)	0.20 (0.008)	Increased	46.72	153.25
23	0.08 (0.003)		Same	48.25	158.25
24	0.08 (0.003)	0.10 (0.004)	Increased	49.47	162.25
25	0.08 (0.003)		Same	50.00	164.00
26	0.08 (0.003)		Same	50.69	166.25
27	0.08 (0.003)		Same	51.75	169.75

28	0.10 (0.004)		Same	57.88	189.93
29	0.10 (0.004)		Same	60.21	197.50
30	0.10 (0.004)		Same	61.51	201.75
31	0.10 (0.004)	0.15 (0.006)	Increased	62.65	205.50
32	0.10 (0.004)		Same	64.28	210.83
33	0.10 (0.004)		Same	65.09	213.50
34	0.10 (0.004)		Same	66.49	218.08
35	< 0.08 (< 0.003)	0.10 (0.004)	Increased	67.07	220.00
36	< 0.08 (< 0.003)	0.15 (0.006)	Increased	68.75	225.50
37	< 0.08 (< 0.003)		Same	74.77	245.25
38	< 0.08 (< 0.003)		Same	75.99	249.25
39	0.08 (0.003)		Same	79.42	260.50
40	0.08 (0.003)		Same	81.55	267.50
41	0.10 (0.004)		Same	81.05	265.83
42	0.10 (0.004)		Same	81.86	268.50
43	0.10 (0.004)		Same	83.23	273.00
44	0.08 (0.003)	0.10 (0.004)	Increased	83.99	275.50
45	0.08 (0.003)		Same	84.76	278.00
46	0.10 (0.004)	0.10 (0.004)	Increased	85.65	280.92
47	0.10 (0.004)		Same	87.96	288.50
48		0.10 (0.004)	New Crack	27.57	90.42
49		0.10 (0.004)	New Crack	56.68	185.92
50		0.15 (0.006)	New Crack	68.80	225.67
51		0.10 (0.004)	New Crack	77.74	255.0
52		0.10 (0.004)	New Crack	93.33	306.12

Cracks 48 to 52 are cracks located for the first time on survey done on 9 -6 - 97.
New Cracks of width less than 0.1 mm (0.0039 inch) located on 9 - 6 - 97 have not been tabulated.

Table F1b: Cracks Located on the Barriers - East Side

Crack No:	Width of Crack (Survey done on 9/ 6/ 97) mm (inch)	Width of Crack (Survey done on 11 /19 /97) mm (inch)	Status of Crack (With respect to width)	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1,	0.10 (0.004)		Same	8.66	28.42
2	0.10 (0.004)		Same	9.60	31.50
3	0.10 (0.004)		Same	14.71	48.25
4	0.10 (0.004)		Same	16.67	54.67
5	0.10 (0.004)		Same	17.84	58.50
6	< 0.08 (< 0.003)		Same	18.75	61.50
7	0.08 (0.003)		Same	19.74	64.75
8	0.10 (0.004)		Same	20.81	68.25
9	< 0.08 (< 0.003)		Same	22.03	72.25
10	0.10 (0.004)		Same	23.25	76.25
11	0.10 (0.004)		Same	77.74	255.0
12	0.40 (0.016)		Same	25.69	84.25
13	0.10 (0.004)		Same	27.57	90.42
14	0.10 (0.004)		Same	28.58	93.75
15	0.15 (0.006)		Same	30.95	101.50
16	0.10 (0.004)		Same	31.55	103.50
17	0.20 (0.008)		Same	33.38	109.50
18	0.20 (0.008)		Same	35.67	117.00
19	0.08 (0.003)		Same	36.13	118.50
20	0.10 (0.004)		Same	38.87	127.50
21	0.08 (0.003)		Same	40.55	133.00
22	0.08 (0.003)		Same	41.62	136.50
23	0.25 (0.01)		Same	44.36	145.50
24	0.20 (0.008)		Same	46.72	153.25
25	0.08 (0.003)		Same	48.25	158.25
26	0.10 (0.004)		Same	49.47	162.25
27	0.08 (0.003)		Same	50.00	164.00

28	0.08 (0.003)		Same	50.69	166.25
29	0.08 (0.003)		Same	51.75	169.75
30	0.10 (0.004)		Same	56.68	185.92
31	0.10 (0.004)		Same	57.88	189.93
32	0.10 (0.004)		Same	60.21	197.50
33	0.10 (0.004)		Same	61.51	201.75
34	0.15 (0.006)		Same	62.65	205.50
35	0.10 (0.004)		Same	64.28	210.83
36	0.10 (0.004)		Same	65.09	213.50
37	0.10 (0.004)		Same	66.49	218.08
38	0.10 (0.004)		Same	67.07	220.00
39	0.15 (0.006)	0.20 (0.008)	Increased	68.75	225.50
40	< 0.08 (< 0.003)		Same	74.77	245.25
41	< 0.08 (< 0.003)		Same	75.99	249.25
42	0.08 (0.003)		Same	79.42	260.50
43	0.08 (0.003)		Same	81.55	267.50
44	0.10 (0.004)		Same	81.05	265.83
45	0.10 (0.004)		Same	81.86	268.50
46	0.10 (0.004)		Same	83.23	273.00
47	0.10 (0.004)		Same	83.99	275.50
48	0.08 (0.003)		Same	84.76	278.00
49	0.10 (0.004)		Same	85.65	280.92
50	0.10 (0.004)		Same	87.96	288.50
51	0.10 (0.004)		Same	93.33	306.12

No new cracks of width greater than 0.1 mm (0.0039 inch) were observed on 11/19/97.

Table F2: Cracks Located on the Barriers – West Side

Crack No:	Width Of Crack (Survey done on 9 - 8- 96) mm (inch)	Width Of Crack (Survey done on 6 - 16- 97) mm (inch)	Status Of Crack (With respect to width)	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	0.08 (0.003)	< 0.08 (< 0.003)	Decreased	23.17	76.00
2	0.08 (0.003)	0.15 (0.006)	Increased	30.42	99.80
3	0.10 (0.004)	0.15 (0.006)	Increased	32.51	106.65
4	0.10 (0.004)	0.15 (0.006)	Increased	34.66	113.70
5	0.10 (0.004)	0.15 (0.006)	Increased	35.81	117.50
6	0.10 (0.004)	0.30 (0.012)	Increased	38.1	125.00
7	< 0.08 (< 0.003)	0.10 (0.004)	Increased	39.47	129.50
8	0.08 (0.003)	< 0.08 (< 0.003)	Decreased	40.63	133.30
9	< 0.08 (< 0.003)	0.08 (0.003)	Increased	43.72	143.45
10	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	48.69	159.75
11	0.08 (0.003)	0.08 (0.003)	Same	53.43	175.30
12	< 0.08 (< 0.003)	0.08 (0.003)	Increased	56.63	185.80
13	0.10 (0.004)	0.08 (0.003)	Decreased	59.13	194.00
14	0.10 (0.004)	0.08 (0.003)	Decreased	60.73	199.25
15	< 0.08 (< 0.003)	0.08 (0.003)	Increased	62.41	204.75
16	< 0.08 (< 0.003)	0.10 (0.004)	Increased	63.64	208.80
17	0.08 (0.003)	0.15 (0.006)	Increased	66.75	219.00
18	< 0.08 (< 0.003)	0.08 (0.003)	Increased	71.63	235.00
19	< 0.08 (< 0.003)	0.08 (0.003)	Increased	73.00	239.50
20	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	74.22	243.50
21	< 0.08 (< 0.003)	0.08 (0.003)	Increased	75.60	248.00
22	< 0.08 (< 0.003)	0.08 (0.003)	Increased	76.58	251.25
23	< 0.08 (< 0.003)	0.08 (0.003)	Increased	77.65	254.75
24	0.08 (0.003)	0.10 (0.004)	Increased	82.30	270.00
25	< 0.08 (< 0.003)	0.08 (0.003)	Increased	83.52	274.00
26	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	85.12	279.25
27	< 0.08 (< 0.003)	0.08 (0.003)	Increased	87.78	288.00

28	< 0.08 (< 0.003)	0.08 (0.003)	Increased	89.92	295.00
29		0.10 (0.004)	New Crack	9.55	31.33
30		0.10 (0.004)	New Crack	16.05	52.67
31		0.10 (0.004)	New Crack	17.75	58.25
32		0.10 (0.004)	New Crack	19.51	64.00
33		0.10 (0.004)	New Crack	50.09	164.33
34		0.10 (0.004)	New Crack	50.67	166.25
35		0.10 (0.004)	New Crack	52.55	172.42
36		0.10 (0.004)	New Crack	62.87	206.25

Cracks 29 to 36 are new cracks found on the inspection on 6 - 16 - 97
New Cracks of width less than 0.1 mm (0.0039 inch) located on 6 - 16 - 97
have not been tabulated.

Table F2a: Cracks Located on the Barriers - West Side

Crack No:	Width of Crack (Survey done on 6 - 16- 97) mm (inch)	Width of Crack (Survey done on 9 - 6- 97) mm (inch)	Status of Crack (With respect to width)	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	0.10 (0.004)		Same	9.55	31.33
2	0.10 (0.004)		Same	16.06	52.67
3	0.10 (0.004)		Same	17.76	58.25
4	0.10 (0.004)		Same	19.51	64.00
5	< 0.08 (< 0.003)		Same	23.17	76.00
6	0.15 (0.006)		Same	30.43	99.80
7	0.15 (0.006)		Same	32.52	106.65
8	0.15 (0.006)	0.20 (0.008)	Increased	34.66	113.70
9	0.15 (0.006)	0.20 (0.008)	Increased	35.82	117.50
10	0.30 (0.012)		Same	38.11	125.00
11	0.10 (0.004)		Same	39.48	129.50
12	< 0.08 (< 0.003)	0.10 (0.004)	Increased	40.64	133.30
13	0.08 (0.003)		Same	43.73	143.45
14	< 0.08 (< 0.003)		Same	48.70	159.75
15	0.10 (0.004)		Same	50.10	164.33
16	0.10 (0.004)		Same	50.69	166.25
17	0.10 (0.004)		Same	52.57	172.42
18	0.08 (0.003)		Same	53.45	175.30
19	0.08 (0.003)		Same	56.65	185.80
20	0.08 (0.003)		Same	59.15	194.00
21	0.08 (0.003)		Same	60.75	199.25
22	0.08 (0.003)	0.10 (0.004)	Increased	62.42	204.75
23	0.10 (0.004)		Same	62.88	206.25
24	0.10 (0.004)		Same	63.66	208.80
25	0.15 (0.006)		Same	66.77	219.00
26	0.08 (0.003)		Same	71.65	235.00
27	0.08 (0.003)		Same	73.02	239.50

28	< 0.08 (< 0.003)		Same	74.24	243.50
31	0.08 (0.003)		Same	75.61	248.00
32	0.08 (0.003)		Same	76.60	251.25
33	0.08 (0.003)		Same	77.67	254.75
34	0.10 (0.004)		Same	82.32	270.00
35	0.08 (0.003)		Same	83.54	274.00
36	< 0.08 (< 0.003)		Same	85.14	279.25
37	0.08 (0.003)		Same	87.80	288.00
38	0.08 (0.003)	0.10 (0.004)	Increased	89.94	295.00
39		0.10 (0.004)	New Crack	14.51	47.60
40		0.10 (0.004)	New Crack	20.55	67.40
41		0.25 (0.010)	New Crack	38.41	126.0
42		0.10 (0.004)	New Crack	46.88	153.75
43		0.10 (0.004)	New Crack	80.26	263.25
44		0.10 (0.004)	New Crack	95.73	314.00

Cracks 39 to 44 are new cracks found on the inspection on 9 - 6 - 97.
New Cracks of width less than 0.1 mm (0.0039 inch) located on 9 - 6 - 97 have not been tabulated.

Table F2b: Cracks Located on the Barriers - West Side

Crack No:	Width of Crack (Survey done on 9/6/97) mm (inch)	Width of Crack (Survey done on 11/19/97) mm (inch)	Status of Crack (With respect to width)	Crack Location (Distances as measured from the north end of concrete barrier) M	(ft)
1	0.10 (0.004)		Same	9.55	31.33
2	0.10 (0.004)		Same	14.51	47.60
3	0.10 (0.004)		Same	16.06	52.67
4	0.10 (0.004)		Same	17.76	58.25
5	0.10 (0.004)		Same	19.51	64.00
6	0.10 (0.004)	0.15 (0.006)	Increased	20.55	67.40
7	< 0.08 (< 0.003)		Same	23.17	76.00
8	0.15 (0.006)		Same	30.43	99.80
9	0.15 (0.006)		Same	32.52	106.65
10	0.20 (0.008)		Same	34.66	113.70
11	0.20 (0.008)		Same	35.82	117.50
12	0.30 (0.012)		Same	38.11	125.00
13	0.25 (0.010)		Same	38.41	126.0
14	0.10 (0.004)		Same	39.48	129.50
15	0.10 (0.004)		Same	40.64	133.30
16	0.08 (0.003)		Same	43.73	143.45
17	0.10 (0.004)		Same	46.88	153.75
18	< 0.08 (< 0.003)		Same	48.70	159.75
19	0.10 (0.004)		Same	50.10	164.33
20	0.10 (0.004)		Same	50.69	166.25
21	0.10 (0.004)		Same	52.57	172.42
22	0.08 (0.003)		Same	53.45	175.30
23	0.08 (0.003)		Same	56.65	185.80
24	0.08 (0.003)		Same	59.15	194.00
25	0.08 (0.003)		Same	60.75	199.25
26	0.10 (0.004)		Same	62.42	204.75
27	0.10 (0.004)		Same	62.88	206.25

28	0.10 (0.004)		Same	63.66	208.80
31	0.15 (0.006)		Same	66.77	219.00
32	0.08 (0.003)		Same	71.65	235.00
33	0.08 (0.003)		Same	73.02	239.50
34	< 0.08 (< 0.003)		Same	74.24	243.50
35	0.08 (0.003)		Same	75.61	248.00
36	0.08 (0.003)		Same	76.60	251.25
37	0.08 (0.003)		Same	77.67	254.75
38	0.10 (0.004)		Same	80.26	263.25
39	0.10 (0.004)		Same	82.32	270.00
40	0.08 (0.003)		Same	83.54	274.00
41	< 0.08 (< 0.003)		Same	85.14	279.25
42	0.08 (0.003)		Same	87.80	288.00
43	0.10 (0.004)		Same	89.94	295.00
44	0.10 (0.004)		Same	95.73	314.00

No new cracks of width greater than 0.1 mm (0.0039 inch) were observed on 11/19/97.

Table F3: Cracks Located on the Deck Slab – East Side

Crack No.	Length of Crack mm (inch)	Width of Crack (Survey done on 9-8-96) mm (inch)	Width of Crack (Survey done on 6-16-97) mm (inch)	Status of Crack	Crack Location (Distances as measured from the North end of Concrete Barrier) m	(ft)
1	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	3.81	12.50
2	305 (12)	< 0.08 (< 0.003)	0.10 (0.004)	Increased	5.49	18.00
3	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	6.78	22.25
4	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	8.84	29.00
* 5	305 (12)	< 0.08 (< 0.003)			10.91	35.80
6	305 (12)	< 0.08 (< 0.003)	0.10 (0.004)	Increased	11.05	36.25
* 7	305 (12)	< 0.08 (< 0.003)			11.34	37.20
8	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	12.27	40.25
9	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	13.49	44.25
10	457 (18)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	14.17	46.50
11	305 (12)	< 0.08 (< 0.003)	0.10 (0.004)	Increased	16.15	53.00
12	914 (36)	0.20 (0.008)	0.15 (0.006)	Decreased	17.45	57.25
13	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	18.59	61.00
14	1524 (60)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	18.96	62.20
15	1524 (60)	0.08 (0.003)	0.08 (0.003)	Same	22.02	72.25
16	610 (24)	< 0.08 (< 0.003)	0.10 (0.004)	Increased	23.17	76.00
17	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	25.98	85.25
18	305 (12)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	27.78	91.15
19	1219 (48)	0.08 (0.003)	0.10 (0.004)	Increased	28.83	94.60
20	1524 (60)	0.30 (0.012)	0.10 (0.004)	Decreased	33.53	110.00
21	1524 (60)	< 0.08 (< 0.003)	0.15 (0.006)	Increased	38.95	127.80
22	610 (24)	0.20 (0.008)	0.10 (0.004)	Decreased	45.11	148.00
23	914 (36)	0.40 (0.016)	0.20 (0.008)	Decreased	50.34	165.15
24	1524 (60)	0.20 (0.008)	0.08 (0.003)	Decreased	50.99	167.30
25	610 (24)	< 0.08 (< 0.003)	0.08 (0.003)	Increased	54.56	179.00
26	1219 (48)	0.15 (0.006)	< 0.08 (<	Decreased	59.13	194.00

			0.003)			
27	1524 (60)	0.20 (0.008)	0.10 (0.004)	Decreased	65.32	214.30
28	914 (36)	< 0.08 (< 0.003)	0.10 (0.004)	Increased	76.81	252.00
29	2134 (84)	0.08 (0.003)	0.15 (0.006)	Increased	81.14	266.20
30	2438 (96)	0.40 (0.016)	0.20 (0.008)	Decreased	82.45	270.50
31	305 (12)	0.10 (0.004)	0.10 (0.004)	Same	84.13	276.00
32	914 (36)	0.15 (0.006)	0.08 (0.003)	Decreased	85.71	281.20
33	305 (12)	< 0.08 (< 0.003)	< 0.08 (< 0.003)	Same	87.17	286.00
** 34			0.10 (0.004)		9.53	31.25
** 35			0.10 (0.004)		19.89	65.25
** 36			0.10 (0.004)		62.69	205.67
** 37			0.10 (0.004)		68.83	225.83

* = Crack (5,7) were not located during survey on 6-16-97.
** = New crack as located on the 6-16-97 inspection.
New Cracks of width less than 0.1 mm (0.0039 inch) located on 6-16-97 have not been tabulated.

Table F3a: Cracks Located on Bridge Deck Slab - East Side

Crack No.	Length of Crack mm (inch)	Width of Crack (Survey done on 6-16-97) mm (inch)	Width of Crack (Survey done on 9-6-97) mm (inch)	Status of Crack	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	305 (12)	0.08 (0.003)		Same	3.81	12.50
2	305 (12)	0.10 (0.004)		Same	5.49	18.00
3	305 (12)	0.08 (0.003)		Same	6.78	22.25
4	305 (12)	0.08 (0.003)	0.10 (0.004)	Increased	8.84	29.00
5		0.10 (0.004)		Same	9.53	31.25
*6	305 (12)				10.91	35.80
7	305 (12)	0.10 (0.004)		Same	11.05	36.25
*8	305 (12)				11.34	37.20
9	305 (12)	0.08 (0.003)		Same	12.27	40.25
10	305 (12)	0.08 (0.003)		Same	13.49	44.25
11	457 (18)	0.08 (0.003)		Same	14.18	46.50
12	305 (12)	0.10 (0.004)	0.15 (0.006)	Increased	16.16	53.00
13	914 (36)	0.15 (0.006)		Same	17.45	57.25
14	305 (12)	0.08 (0.003)		Same	18.60	61.00
15	1524 (60)	0.08 (0.003)		Same	18.96	62.20
16		0.10 (0.004)		Same	19.89	65.25
17	1524 (60)	0.08 (0.003)		Same	22.03	72.25
18	610 (24)	0.10 (0.004)	0.15 (0.006)	Increased	23.17	76.00
19	305 (12)	0.08 (0.003)		Same	25.99	85.25
20	305 (12)	0.08 (0.003)		Same	27.79	91.15
21	1219 (48)	0.10 (0.004)		Same	28.84	94.60
22	1524 (60)	0.10 (0.004)		Same	33.54	110.00
23	1524 (60)	0.15 (0.006)		Same	38.96	127.80
24	610 (24)	0.10 (0.004)		Same	45.12	148.00
25	914 (36)	0.20 (0.008)		Same	50.35	165.15
26	1524 (60)	0.08 (0.003)		Same	51.01	167.30

27	610 (24)	0.08 (0.003)		Same	54.57	179.00
28	1219 (48)	< 0.08 (< 0.003)		Same	59.15	194.00
29		0.10 (0.004)		Same	62.70	205.67
30	1524 (60)	0.10 (0.004)		Same	65.34	214.30
31		0.10 (0.004)		Same	68.85	225.83
32	914 (36)	0.10 (0.004)		Same	76.83	252.00
33	2134 (84)	0.15 (0.006)		Same	81.16	266.20
34	2438 (96)	0.20 (0.008)		Same	82.47	270.50
35	305 (12)	0.10 (0.004)		Same	84.15	276.00
36	914 (36)	0.08 (0.003)	0.10 (0.004)	Increased	85.73	281.20
37	305 (12)	< 0.08 (< 0.003)		Same	87.20	286.00

* = Crack (6,8) were not located during survey on 6-16-97 and 9-6-97.
New Cracks of width less than 0.1 mm (0.0039 inch) located on 6-16-97 and 9-6-97 have not been tabulated.

Table F4: Cracks Located on the Deck Slab – West Side

Crack No:	Length Of Crack mm (inch)	Width Of Crack (Survey done on 9-8-96) mm (inch)	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	610 (24)	0.10 (0.004)	12.54	41.15
2	610 (24)	0.08 (0.003)	16.76	55.00
3	914 (36)	0.10 (0.004)	18.06	59.25
4	610 (24)	0.20 (0.008)	18.90	62.00
5	610 (24)	0.20 (0.008)	20.12	66.00
6	762 (30)	0.20 (0.008)	21.40	70.20
7	457 (18)	0.10 (0.004)	23.77	78.00
8	1067 (42)	0.20 (0.008)	27.13	89.00
9	1219 (48)	0.20 (0.008)	30.18	99.00
10	610 (24)	0.10 (0.004)	32.31	106.00
11	2438 (96)	< 0.08 (< 0.003)	34.49	113.15
12	305 (12)	0.10 (0.004)	35.66	117.00
13	1524 (60)	0.40 (0.016)	37.80	124.00
14	1219 (48)	0.25 (0.014)	40.23	132.00
15	914 (36)	< 0.08 (< 0.003)	42.46	139.30
16	1067 (42)	0.10 (0.004)	46.27	151.80
17	914 (36)	0.15 (0.006)	49.33	161.85
18	914 (36)	0.20 (0.008)	51.21	168.00
19	1067 (42)	0.08 (0.003)	52.97	173.80
20	305 (12)	0.08 (0.003)	53.95	177.00
21	914 (36)	0.08 (0.003)	58.77	192.80
22	610 (24)	0.08 (0.003)	61.88	203.00
23	762 (30)	< 0.08 (< 0.003)	64.07	210.20
24	305 (12)	< 0.08 (< 0.003)	66.75	219.00
25	1372 (54)	0.10 (0.004)	69.04	226.50
26	457 (18)	0.15 (0.006)	74.07	243.00
27	610 (24)	0.15 (0.006)	76.44	250.80

28	229 (9)	0.08 (0.003)	79.78	261.75
29	457 (18)	0.10 (0.004)	82.30	270.00
30	1067 (42)	0.30 (0.016)	83.58	274.20
31	457 (18)	0.20 (0.008)	88.70	291.00
32	305 (12)	< 0.08 (< 0.003)	91.14	299.00

Table F4a: Cracks Located on Bridge Deck Slab - West Side

Crack No:	Length of Crack mm (inch)	Width of Crack (Survey done on 9-8-96) mm (inch)	Width of Crack (Survey done on 9-6-97) mm (inch)	Status of Crack	Crack Location (Distances as measured from the north end of concrete barrier) m	(ft)
1	610 (24)	0.10 (0.004)		Same	12.55	41.15
2	610 (24)	0.08 (0.003)		Same	16.77	55.00
3	914 (36)	0.10 (0.004)	0.15 (0.006)	Increased	18.06	59.25
4	610 (24)	0.20 (0.008)		Same	18.90	62.00
5	610 (24)	0.20 (0.008)		Same	20.12	66.00
6	762 (30)	0.20 (0.008)		Same	21.40	70.20
7	457 (18)	0.10 (0.004)		Same	23.78	78.00
8	1067 (42)	0.20 (0.008)		Same	27.13	89.00
9	1219 (48)	0.20 (0.008)		Same	30.18	99.00
10	610 (24)	0.10 (0.004)	0.15 (0.006)	Increased	32.32	106.00
11	2438 (96)	< 0.08 (< 0.003)	0.10 (0.006)	Increased	34.50	113.15
12	305 (12)	0.10 (0.004)	0.15 (0.006)	Increased	35.67	117.00
13	1524 (60)	0.40 (0.016)		Same	37.80	124.00
14	1219 (48)	0.25 (0.014)		Same	40.24	132.00
15	914 (36)	< 0.08 (< 0.003)	0.15 (0.006)	Increased	42.47	139.30
16	1067 (42)	0.10 (0.004)		Same	46.28	151.80
17	914 (36)	0.15 (0.006)		Same	49.34	161.85
18	914 (36)	0.20 (0.008)		Same	51.22	168.00
19	1067 (42)	0.08 (0.003)		Same	52.99	173.80
20	305 (12)	0.08 (0.003)	0.10 (0.004)	Increased	53.96	177.00
21	914 (36)	0.08 (0.003)	0.15 (0.004)	Increased	58.78	192.80
22	610 (24)	0.08 (0.003)	0.10 (0.004)	Increased	61.89	203.00
23	762 (30)	< 0.08 (< 0.003)		Same	64.09	210.20
24	305 (12)	< 0.08 (< 0.003)	0.15 (0.006)	Increased	66.77	219.00
25	1372 (54)	0.10 (0.004)		Same	69.05	226.50
26	457 (18)	0.15 (0.006)		Same	74.09	243.00
27	610 (24)	0.15 (0.006)		Same	76.46	250.80

28	229 (9)	0.08 (0.003)	0.10 (0.004)	Increased	79.80	261.75
29	457 (18)	0.10 (0.004)		Same	82.32	270.00
30	1067 (42)	0.30 (0.016)		Same	83.60	274.20
31	457 (18)	0.20 (0.008)		Same	88.72	291.00
32	305 (12)	< 0.08 (< 0.003)	0.15 (0.006)	Increased	91.16	299.00
33	610 (24)		0.10	New Crack	25.86	84.83
34	1024 (42)		0.10	New Crack	38.31	125.67
35	610 (24)		0.20	New Crack	40.90	134.16
36	1219 (48)		0.10	New Crack	44.28	145.25
37	610 (24)		0.15	New Crack	48.07	157.67
38	610 (24)		0.15	New Crack	71.09	233.16
39	1219 (48)		0.10	New Crack	77.77	255.08
40	914 (36)		0.10	New Crack	90.42	296.58
41	914 (36)		0.10	New Crack	93.80	307.67
42	914 (36)		0.10	New Crack	95.73	314.00

Cracks 33 to 42 are new cracks found on the inspection done on 9-6-97.
New Cracks of width less than 0.1mm (0.0039 inch) located on 9-6-97 have not been tabulated.

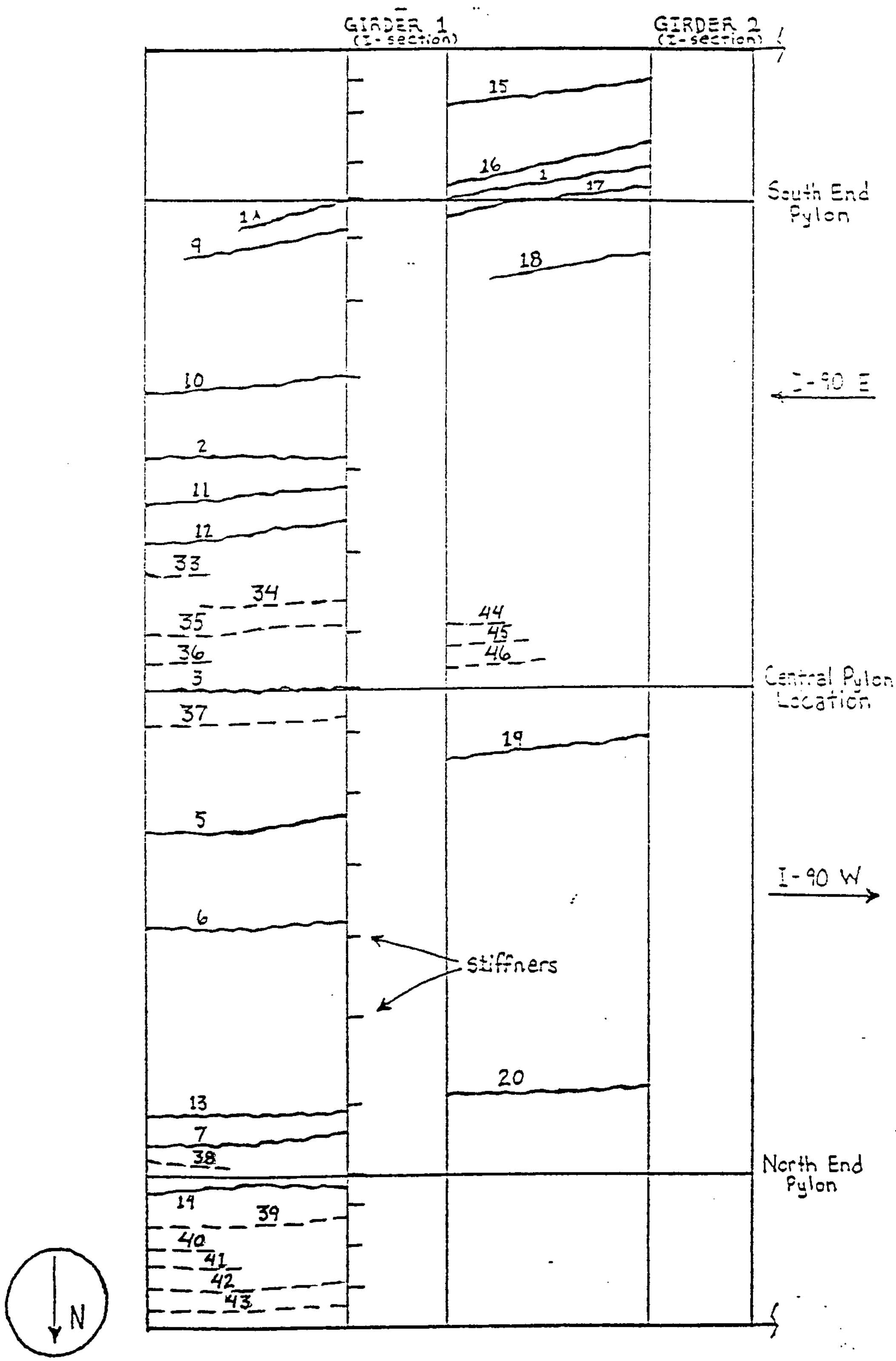
Table F5: Cracks Located on the Bridge Deck Slab – Bottom Surface

Crack No	**Length of Crack** Survey done on June 4,5, 96 **mm (inches)**	**Length of Crack** Survey done on June 16, 97 **mm (inches)**	**Status of Crack**	**Average Width** Survey done on June 3,4, 96 **mm (inches)**	**Average Width** Survey done on June 16, 97 **mm (inches)**	**Status of Crack**
1.	2781 (109.5)	4229 (166.5)	Increased	0.12 (0.005)	0.20 (0.008)	Increased
1A.	1000 (39.4)	1181 (46.5)	Increased	0.10 (0.004)	0.15 (0.006)	Increased
2.	1000 (39.4)	1181 (46.5)	Increased	0.18 (0.007)	0.10 (0.004)	Decreased
3.	1000 (39.4)	1181 (46.5)	Increased	0.13 (0.005)	0.11 (0.004)	Decreased
4.	2235 (88.0)	not measured		hairline crack	not measured	
5.	1000 (39.4)	1181 (46.5)	Increased	0.08 (0.003)	0.10 (0.004)	Increased
6.	1000 (39.4)	1181 (46.5)	Increased	0.09 (0.003)	0.15 (0.006)	Increased
7.	1000 (39.4)	1181 (46.5)	Increased	0.23 (0.009)	0.13 (0.005)	Decreased
8.	2565 (101.0)	not measured		0.13 (0.005)	not measured	
9.	1000 (39.4)	1181 (46.5)	Increased	0.08 (0.003)	0.08 (0.003)	Same
10.	1000 (39.4)	1181 (46.5)	Increased	0.10 (0.004)	0.09 (0.004)	Decreased
11.	1000 (39.4)	1181 (46.5)	Increased	0.12 (0.005)	0.09 (0.004)	Decreased
12.	1000 (39.4)	1181 (46.5)	Increased	0.10 (0.004)	0.15 (0.006)	Increased
13.	1000 (39.4)	1181 (46.5)	Increased	0.20 (0.008)	0.15 (0.006)	Decreased
14.	1000 (39.4)	1181 (46.5)	Increased	0.09 (0.003)	0.09 (0.003)	Same
15.	2235 (88.0)	2235 (88.0)	Same	0.08 (0.003)	0.5 (0.020)	Increased
16.	2235 (88.0)	2235 (88.0)	Same	0.4 (0.016)	0.4 (0.016)	Increased
17.	2235 (88.0)	not measured		0.5 (0.020)	not measured	
18.	1196 (47.1)	2235 (88.0)	Increased	0.15 (0.006)	0.1 (0.004)	Decreased
19.	2235 (88.0)	not measured		0.22 (0.008)	not measured	
20.	2235 (88.0)	not measured		0.53 (0.021)	not measured	
21.	2235 (88.0)	not measured		0.44 (0.017)	not measured	
22.	1399 (55.1)	not measured		0.09 (0.003)	not measured	
23.	2235 (88.0)	not measured		0.17 (0.007)	not measured	
24.	2235 (88.0)	not measured		0.23 (0.009)	not measured	
25.	2235 (88.0)	not measured		0.15 (0.006)	not measured	
26.	2235 (88.0)	not measured		0.27 (0.011)	not measured	
27.	2235 (88.0)	not measured		0.17 (0.007)	not measured	
28.	650 (25.6)	2235 (88.0)	Increased	0.08 (0.003)	not measured	
29.	1915 (75.4)	not measured		0.20 (0.008)	not measured	
30.	2235 (88.0)	not measured		0.13 (0.005)	not measured	
31.	2235 (88.0)	not measured		0.28 (0.011)	not measured	
32.	599 (23.6)	not measured		0.80 (0.031)	not measured	
*33		483 (19.0)			0.10 (0.004)	
*34		1016 (40.0)			0.10 (0.004)	
*35		1168 (46.0)			0.12 (0.005)	
*36		470 (18.5)			0.10 (0.004)	
*37		1181 (46.5)			0.10 (0.004)	
*38		940 (37.0)			0.10 (0.004)	
*39		1181 (46.5)			0.13 (0.005)	

*40		686 (27.0)			0.20 (0.008)	
*41		457 (18.0)			0.15 (0.006)	
*42		1181 (46.5)			0.20 (0.008)	
*43		1181 (46.5)			0.15 (0.006)	
*44		686 (27.0)			0.15 (0.006)	
*45		533 (21.0)			0.10 (0.004)	
*46		1219 (48.0)			0.13 (0.005)	
*47		2235 (88.0)			0.30 (0.012)	
*48		2235 (88.0)			0.37 (0.014)	
*49		2235 (88.0)			0.15 (0.006)	
*50		2235 (88.0)			0.13 (0.005)	
*51		2235 (88.0)			0.12 (0.005)	
*52		2235 (88.0)			0.20 (0.008)	
*53		2235 (88.0)			0.10 (0.004)	
*54		1981 (78.0)			0.14 (0.006)	
*55		2235 (88.0)			0.12 (0.005)	
*56		2235 (88.0)			0.15 (0.006)	
*57		2235 (88.0)			0.10 (0.004)	
*58		2235 (88.0)			0.22 (0.009)	
*59		2235 (88.0)			0.12 (0.005)	
*60		1981 (78.0)			0.22 (0.009)	
*61		1181 (46.5)			0.18 (0.007)	
*62		1181 (46.5)			0.18 (0.007)	
*63		1181 (46.5)			0.15 (0.006)	
*64		1181 (46.5)			0.13 (0.005)	
*65		1181 (46.5)			0.12 (0.005)	
*66		1181 (46.5)			0.13 (0.005)	
*67		1181 (46.5)			0.12 (0.005)	
*68		1181 (46.5)			0.20 (0.008)	
*69		1181 (46.5)			0.16 (0.006)	
*70		1181 (46.5)			0.12 (0.005)	
*71		1181 (46.5)			0.18 (0.007)	
*72		1181 (46.5)			0.18 (0.007)	
*73		1181 (46.5)			0.15 (0.006)	
*74		546 (21.5)			0.13 (0.005)	
*75		648 (25.5)			0.18 (0.007)	
*76		432 (17.0)			0.15 (0.006)	
*77		889 (35.0)			0.16 (0.006)	
*78		1181 (46.5)			0.18 (0.007)	
*79		1181 (46.5)			0.20 (0.008)	
*80		1181 (46.5)			0.18 (0.007)	
*81		1181 (46.5)			0.12 (0.005)	
*82		1181 (46.5)			0.16 (0.006)	
*83		889 (35.0)			0.10 (0.004)	
*84		1181 (46.5)			0.12 (0.005)	
*85		699 (27.5)			0.14 (0.006)	
*86		1181 (46.5)			0.18 (0.007)	
*87		1181 (46.5)			0.14 (0.006)	

*88		762 (30.0)			0.15 (0.006)	
*89		1181 (46.5)			0.14 (0.006)	
*90		432 (17.0)			0.13 (0.005)	
*91		1181 (46.5)			0.18 (0.007)	
*92		1181 (46.5)			0.20 (0.008)	
*93		1181 (46.5)			0.12 (0.005)	
*94		686 (27.0)			0.14 (0.006)	
*95		1181 (46.5)			0.12 (0.005)	
*96		1181 (46.5)			0.15 (0.006)	
*97		1181 (46.5)			0.14 (0.006)	
*98		1181 (46.5)			0.12 (0.005)	
*99		1181 (46.5)			0.14 (0.006)	
*100		1181 (46.5)			0.13 (0.005)	

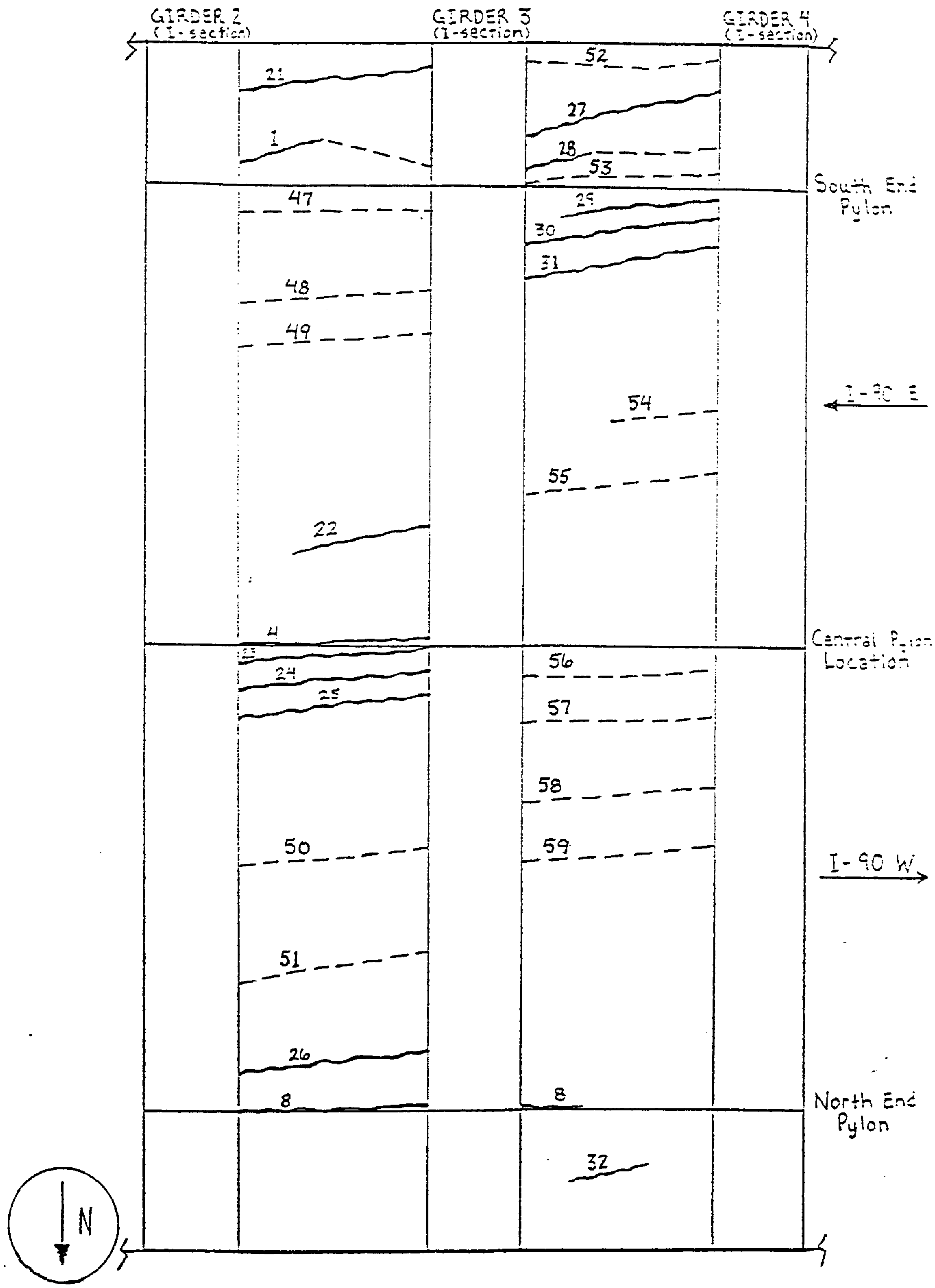
* Cracks located for the first time on 6-16-1997.
Crack locations are shown in the sketches.
New Cracks of width less than 0.1 mm (0.0039 inch), located on 6-16-97 have not been tabulated or shown on the sketches.



Cracks measured on June 3,4, 1996. Broken lines - cracks measured on June 16, 1997.

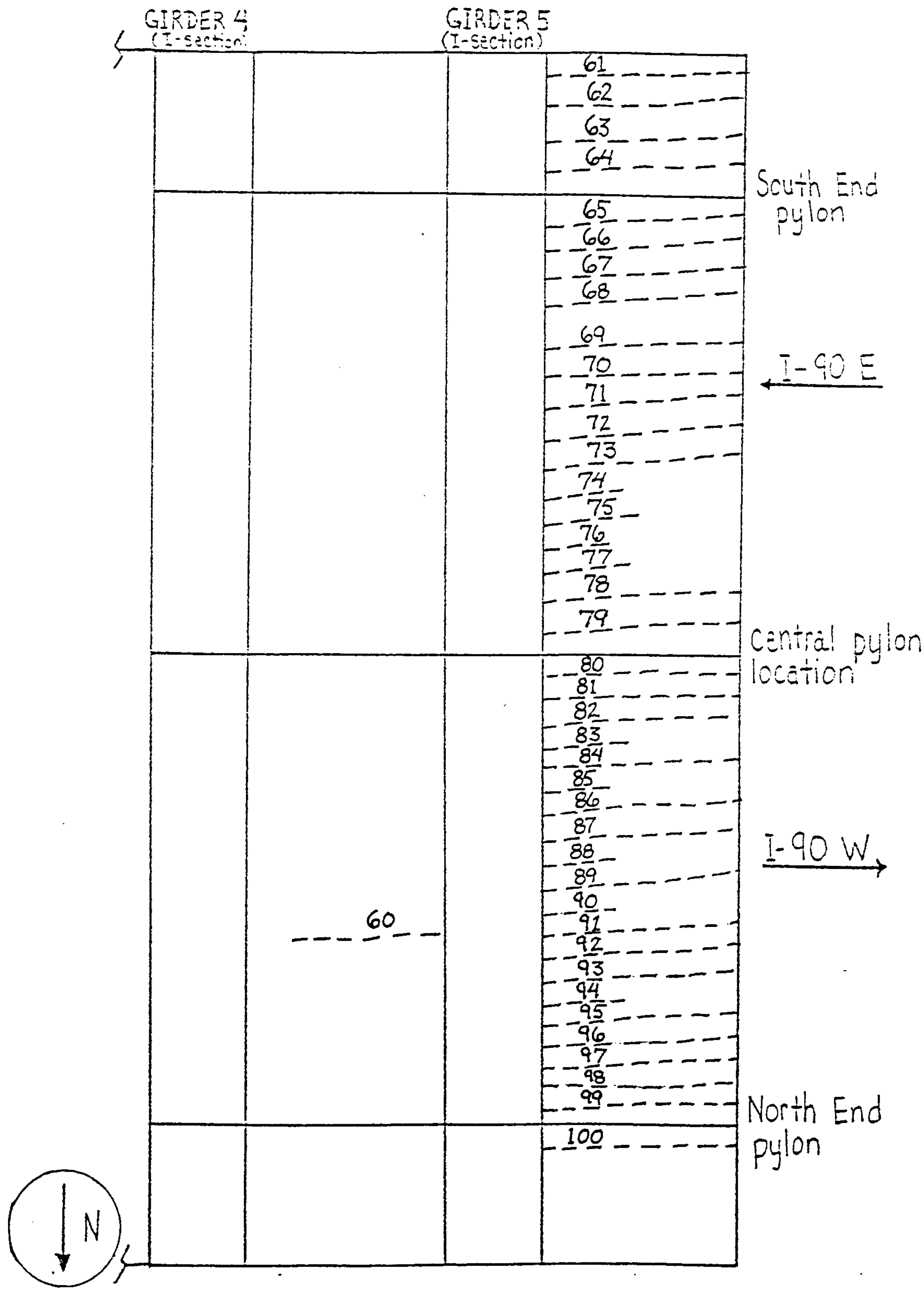
(Not to scale)

Sketch No. 1A Details Of Cracks In Bridge Deck Slab - Bottom Surface



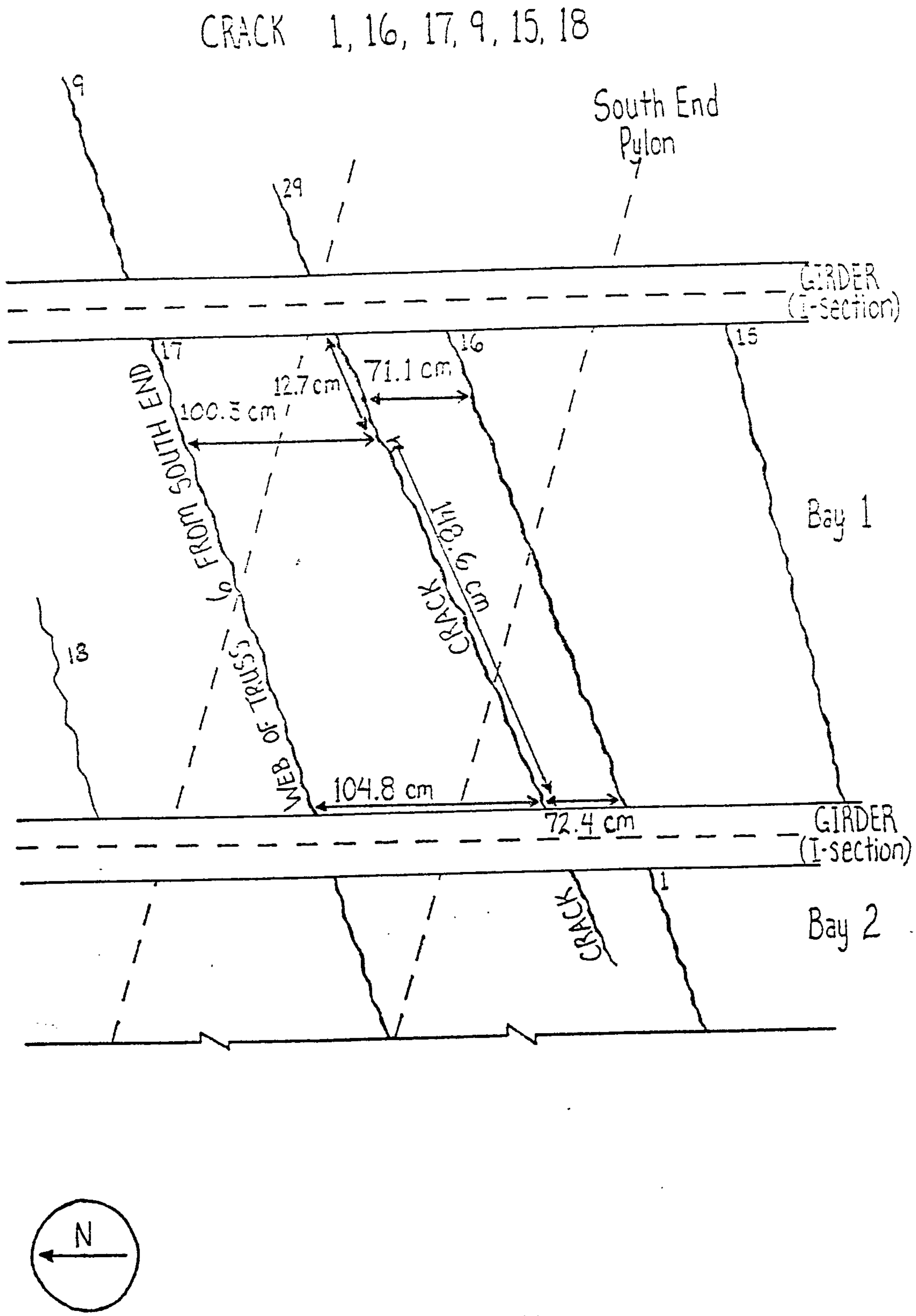
(Not to scale)

Sketch No. 1B Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



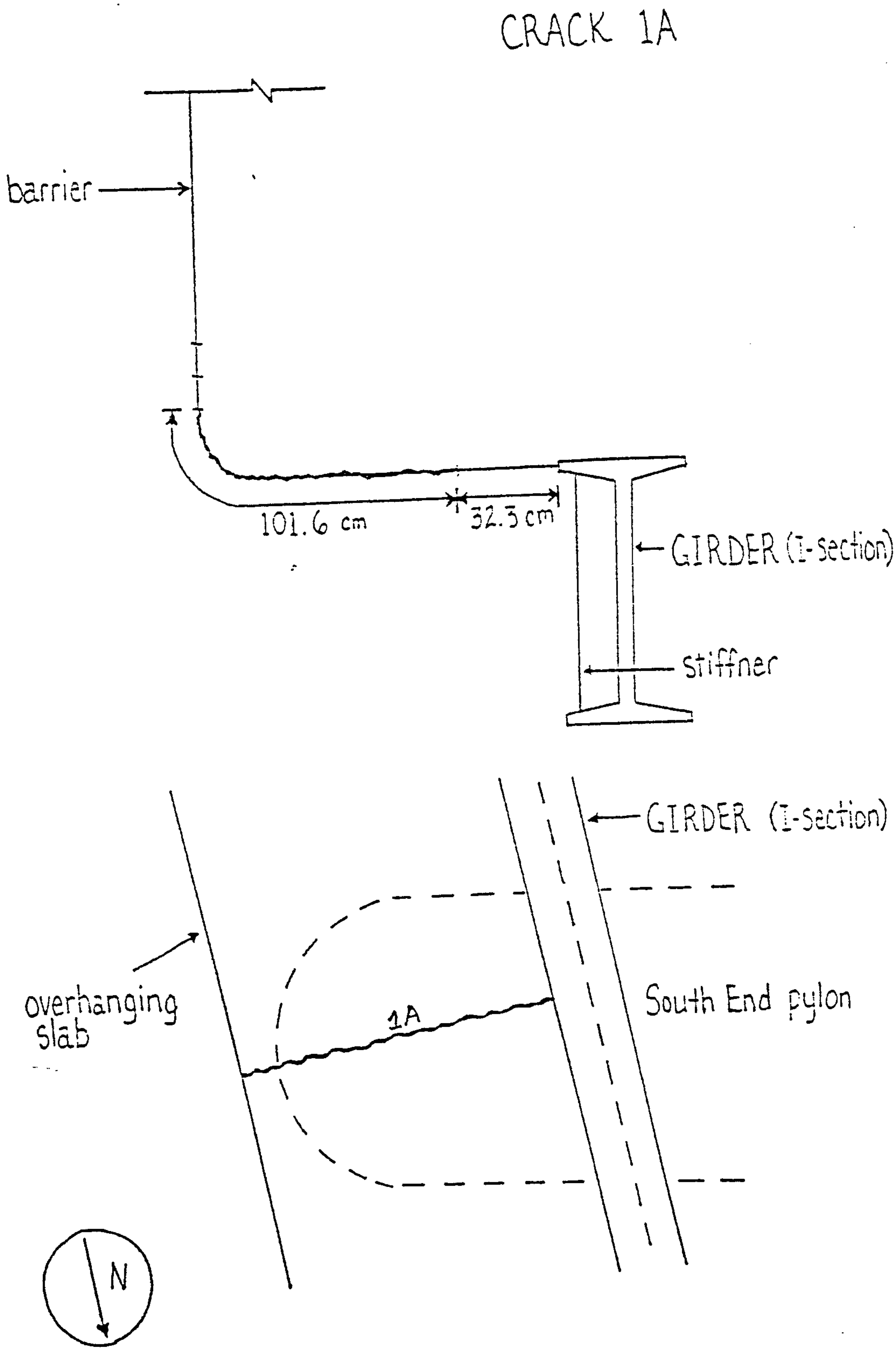
(Not to scale)

Sketch No. 1C Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



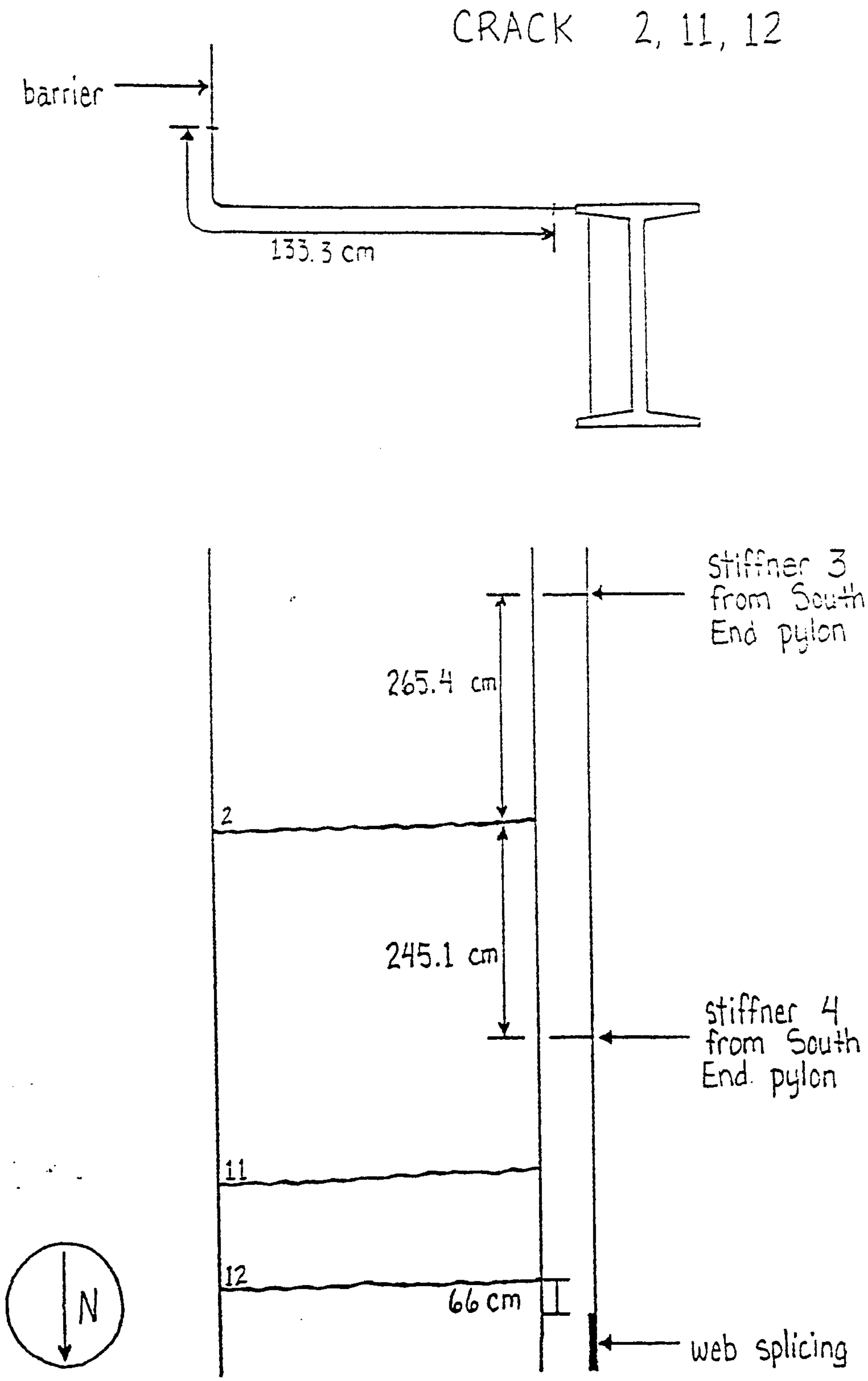
(Not to scale)

Sketch No. 1D Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



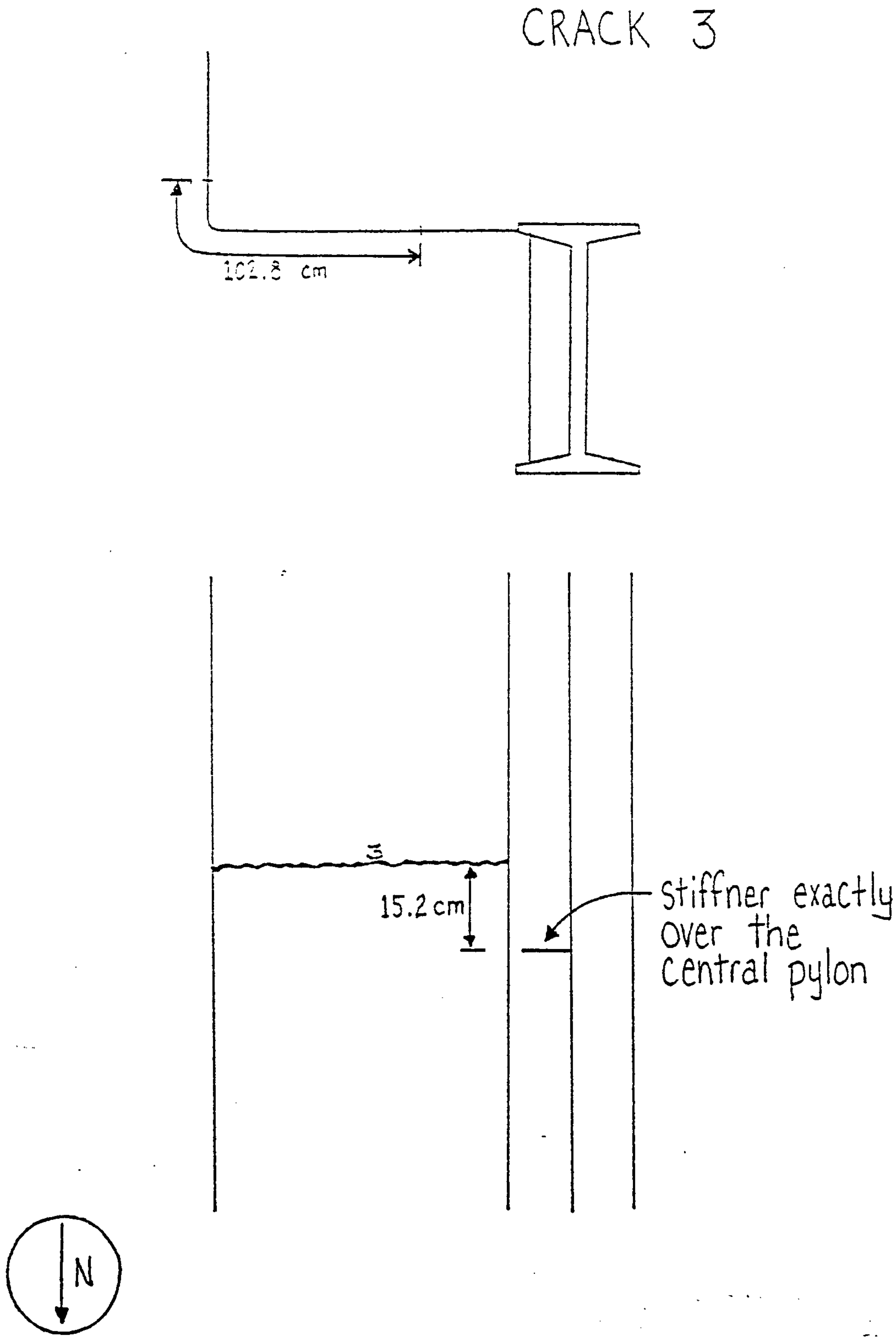
(Not to scale)

Sketch No. 1E Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



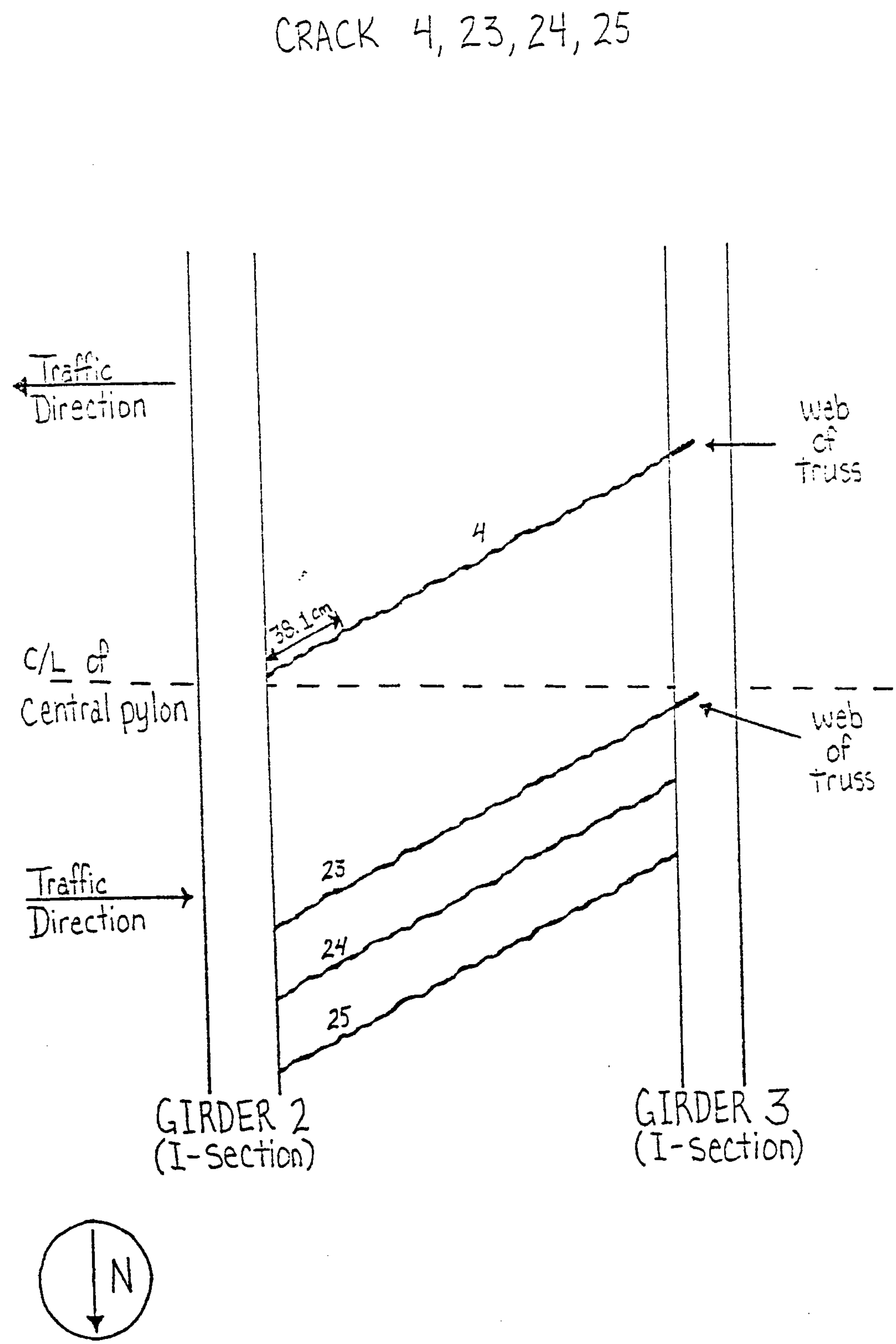
(Not to scale)

Sketch No. 1F Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

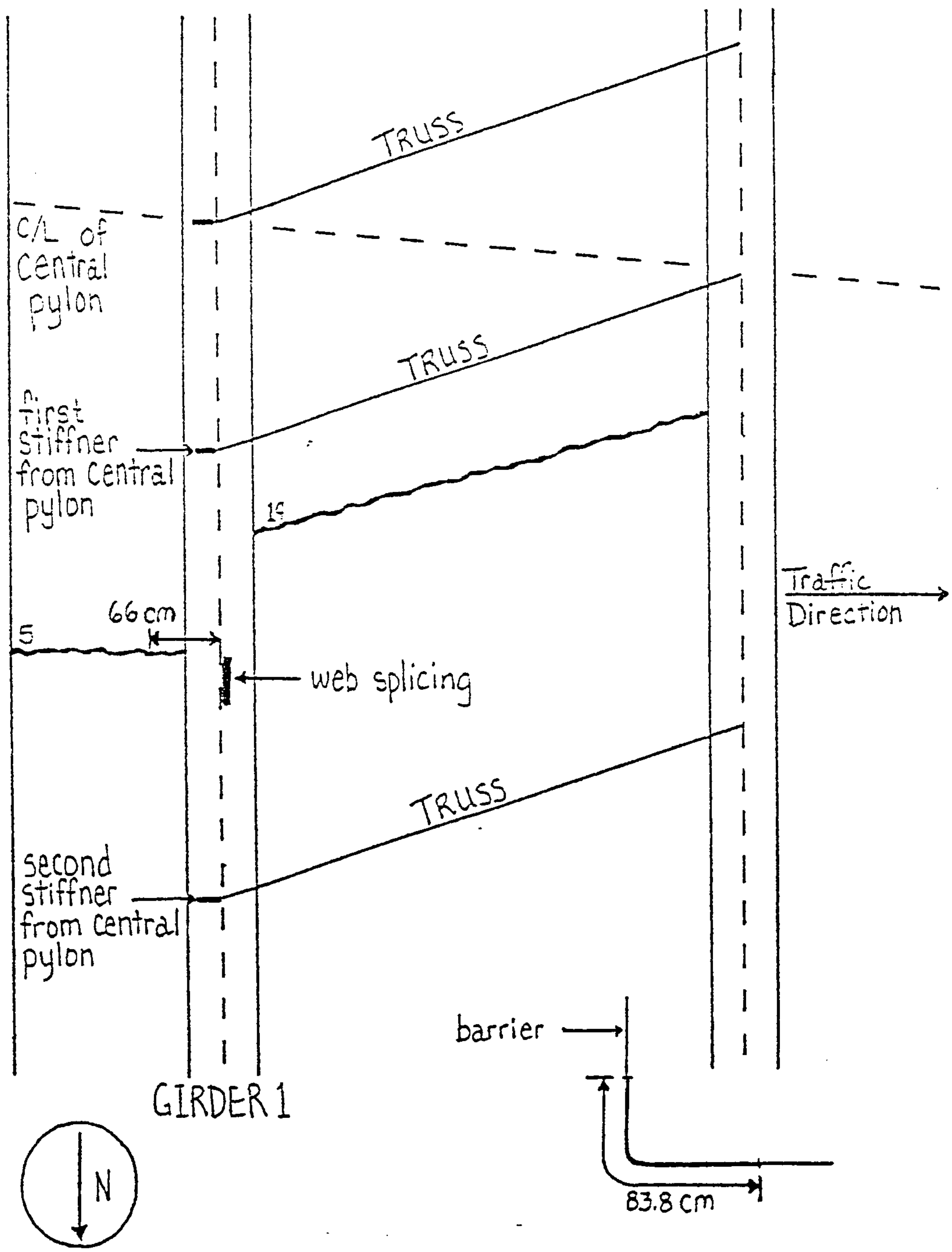
Sketch No. 1G Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

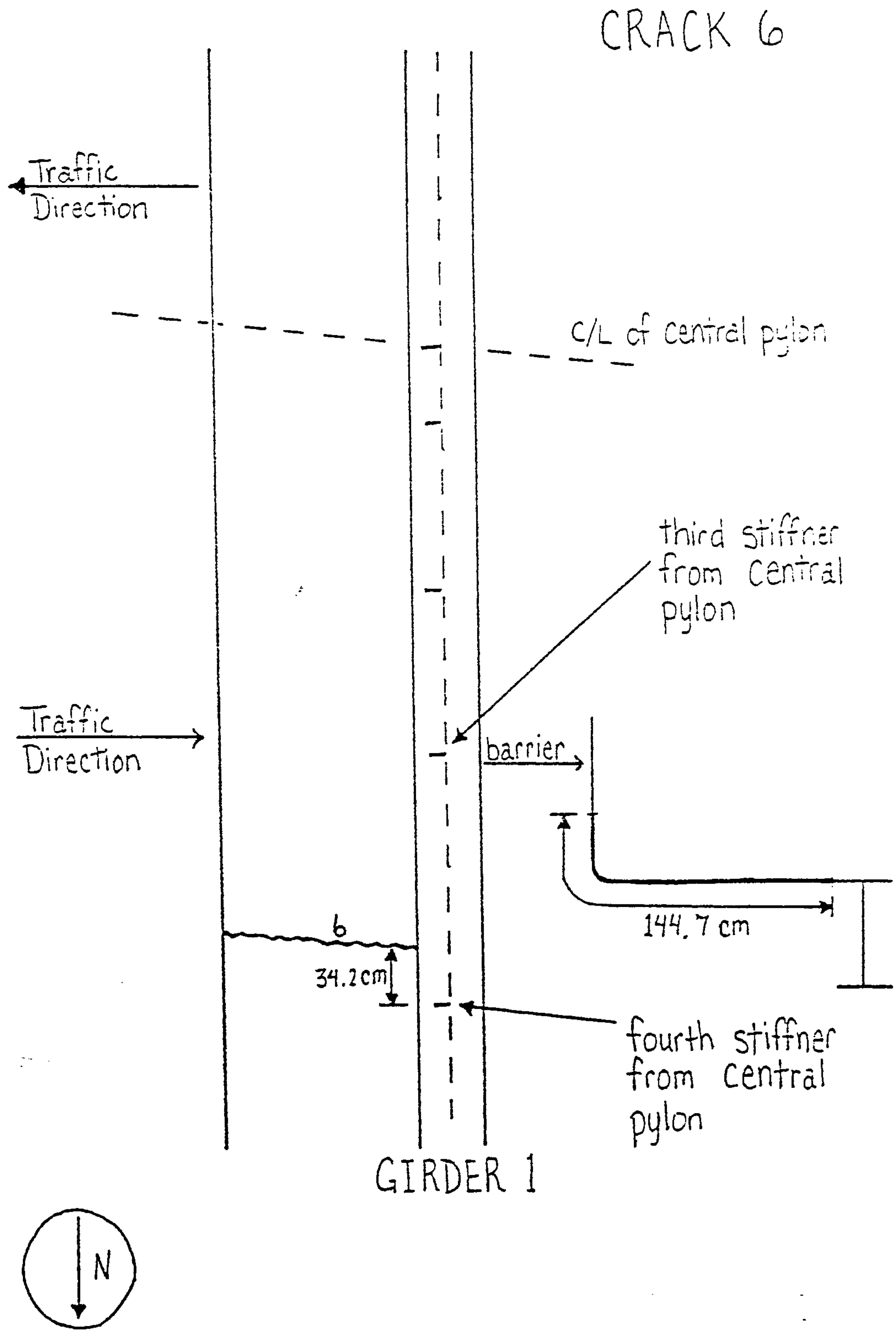
Sketch No. 1H Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)

CRACK 5, 19



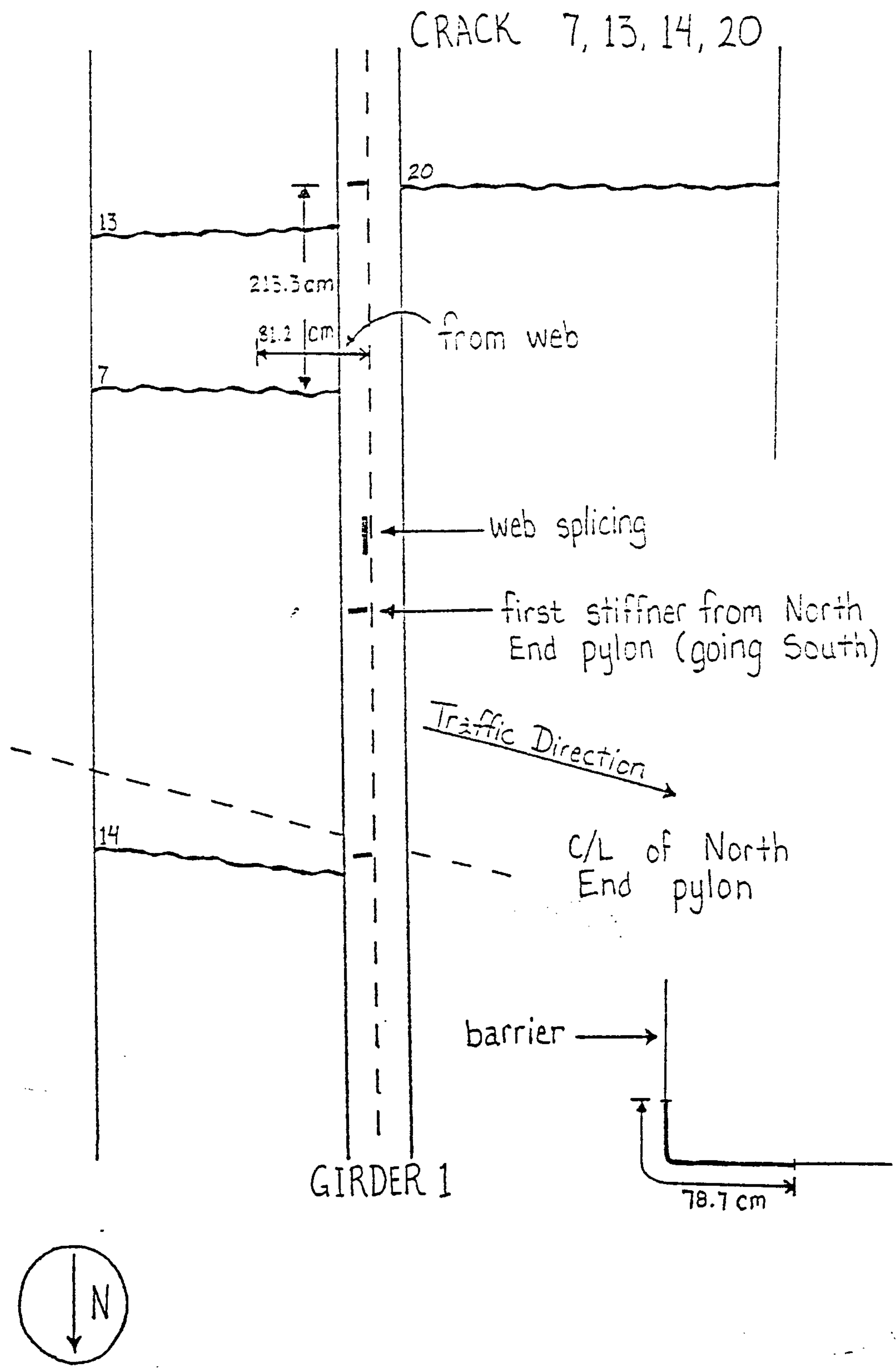
(Not to scale)

Sketch No. 1I Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

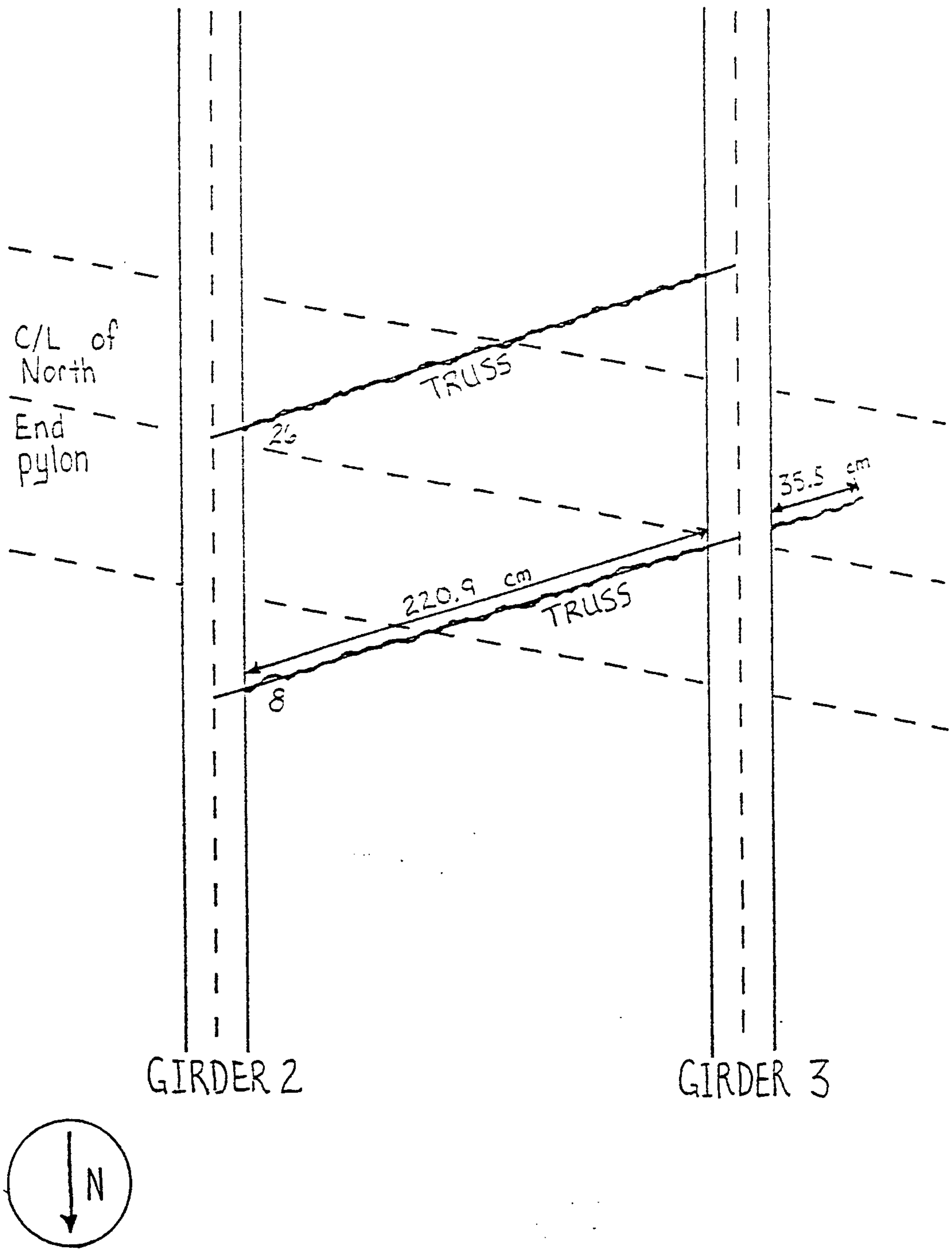
Sketch No. 1J Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

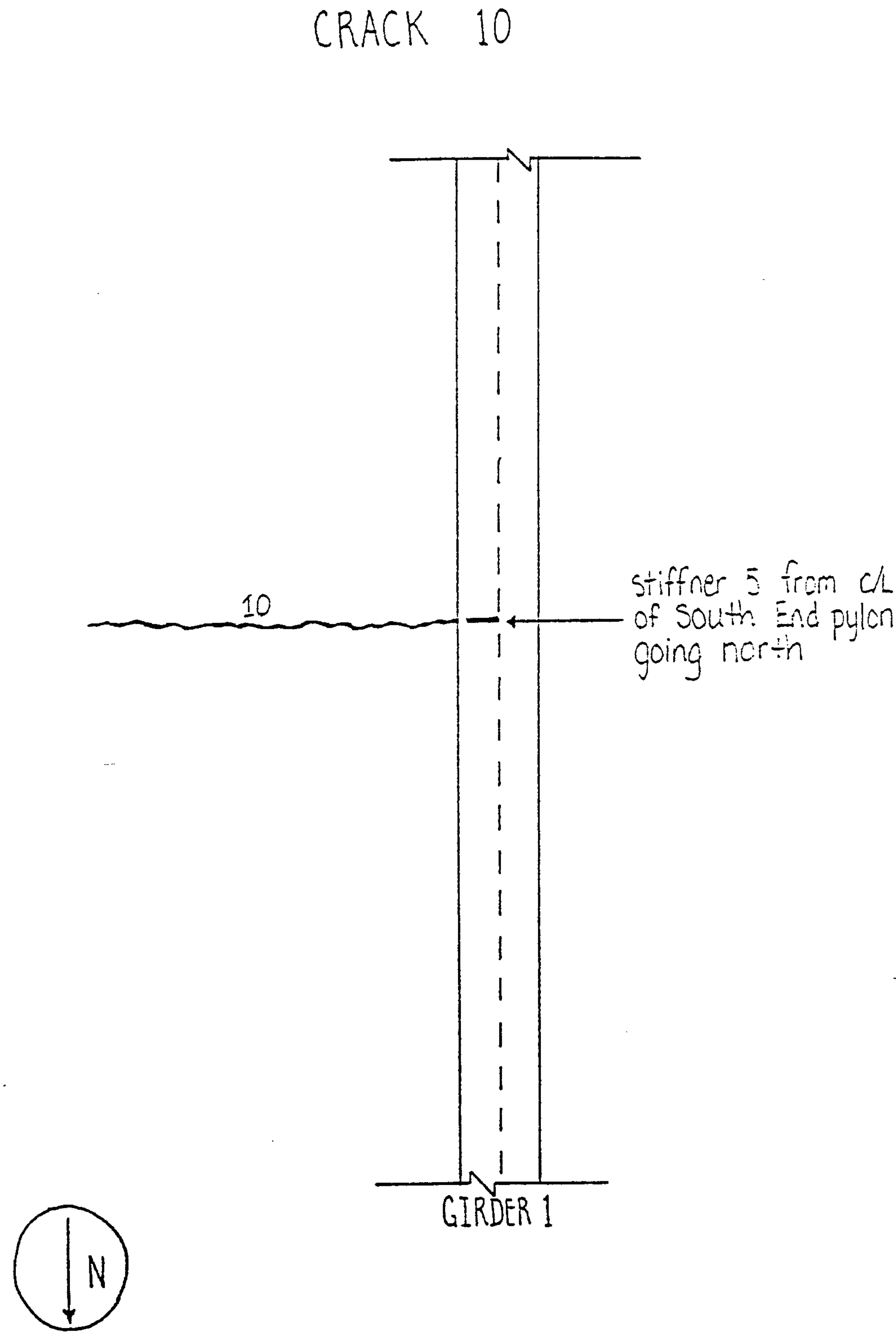
Sketch No. 1K Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)

CRACK 8, 26



(Not to scale)

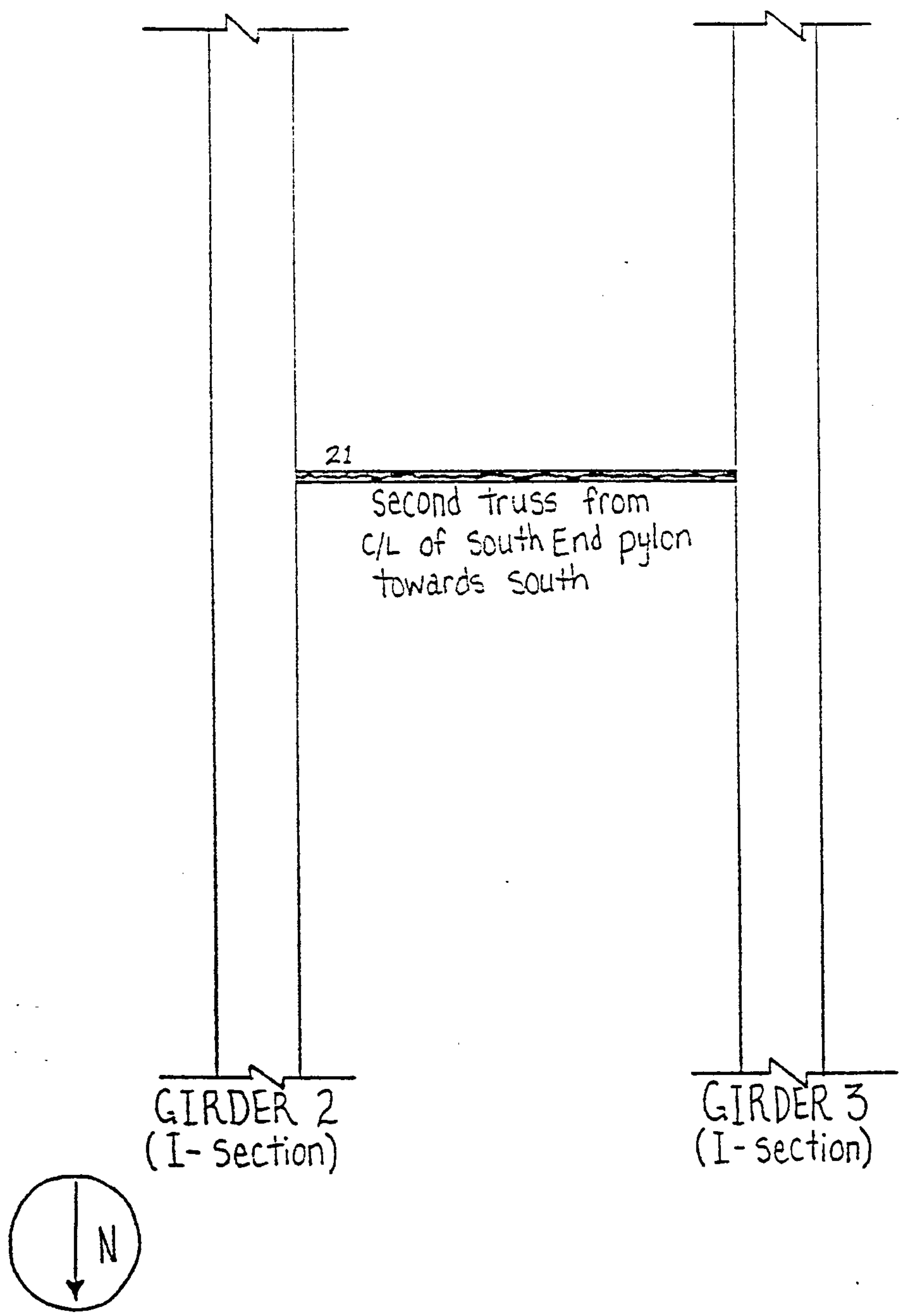
Sketch No. 1L Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

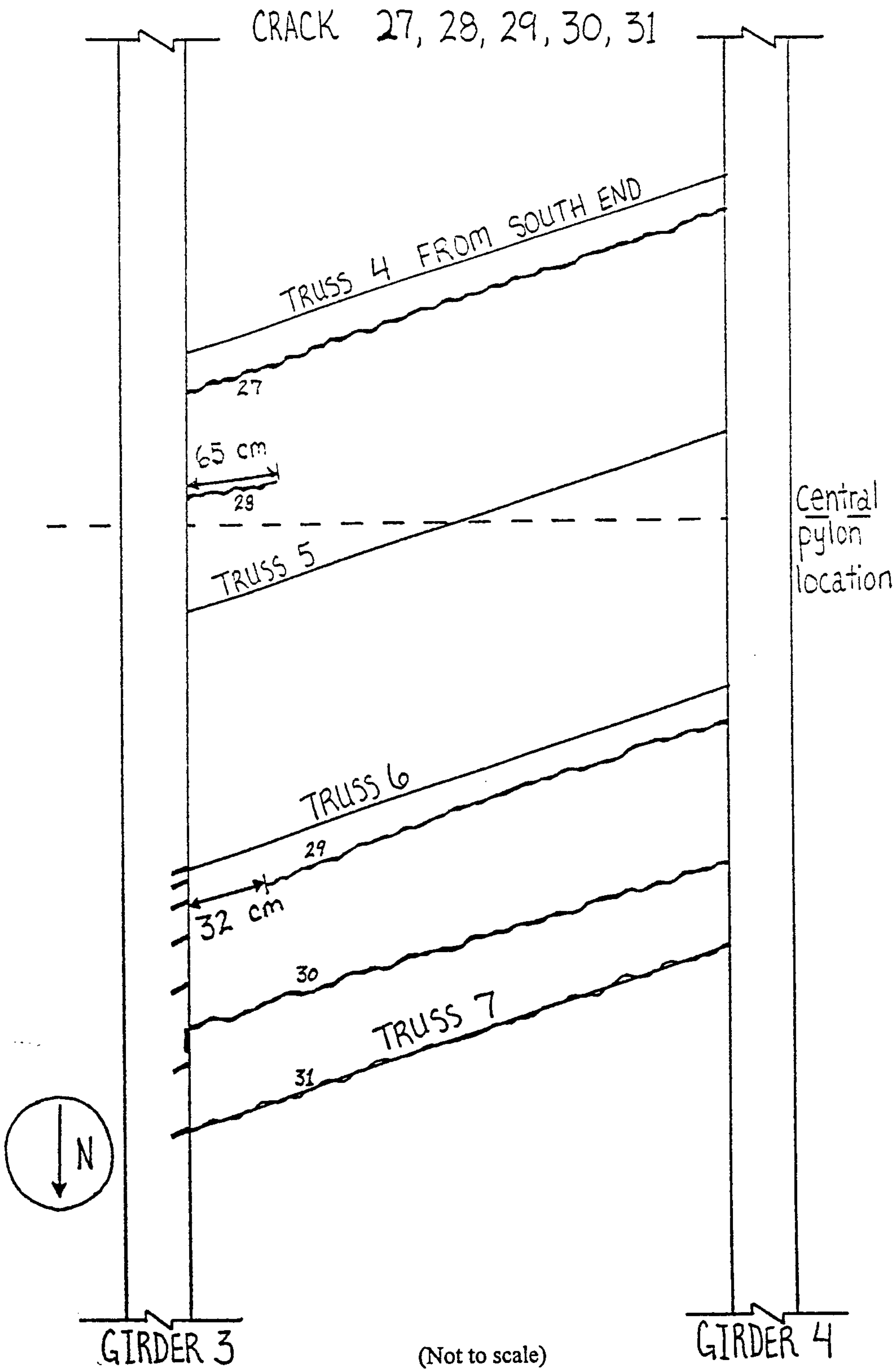
Sketch No. 1M Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)

CRACK 21



(Not to scale)

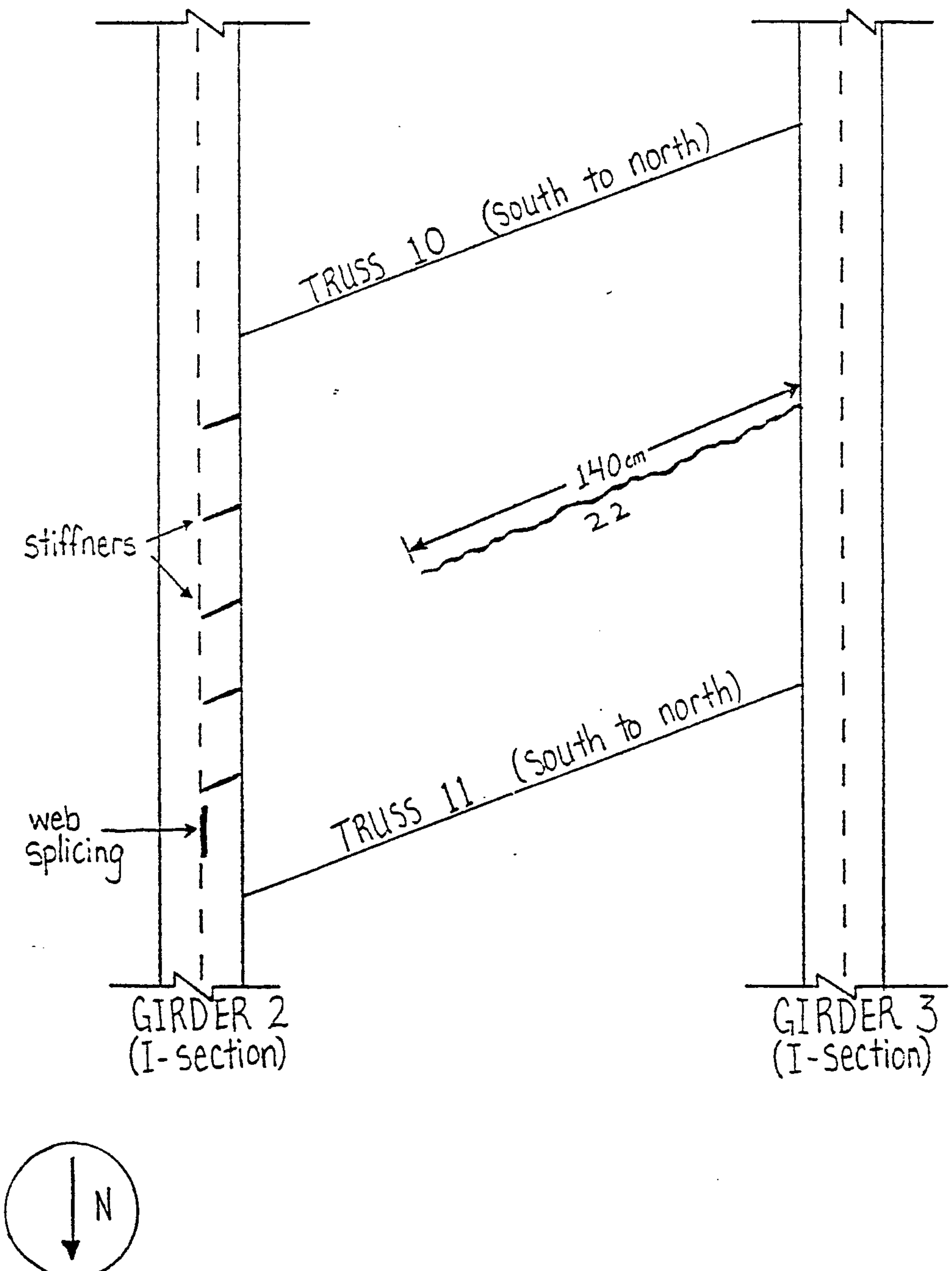
Sketch No. 1N Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

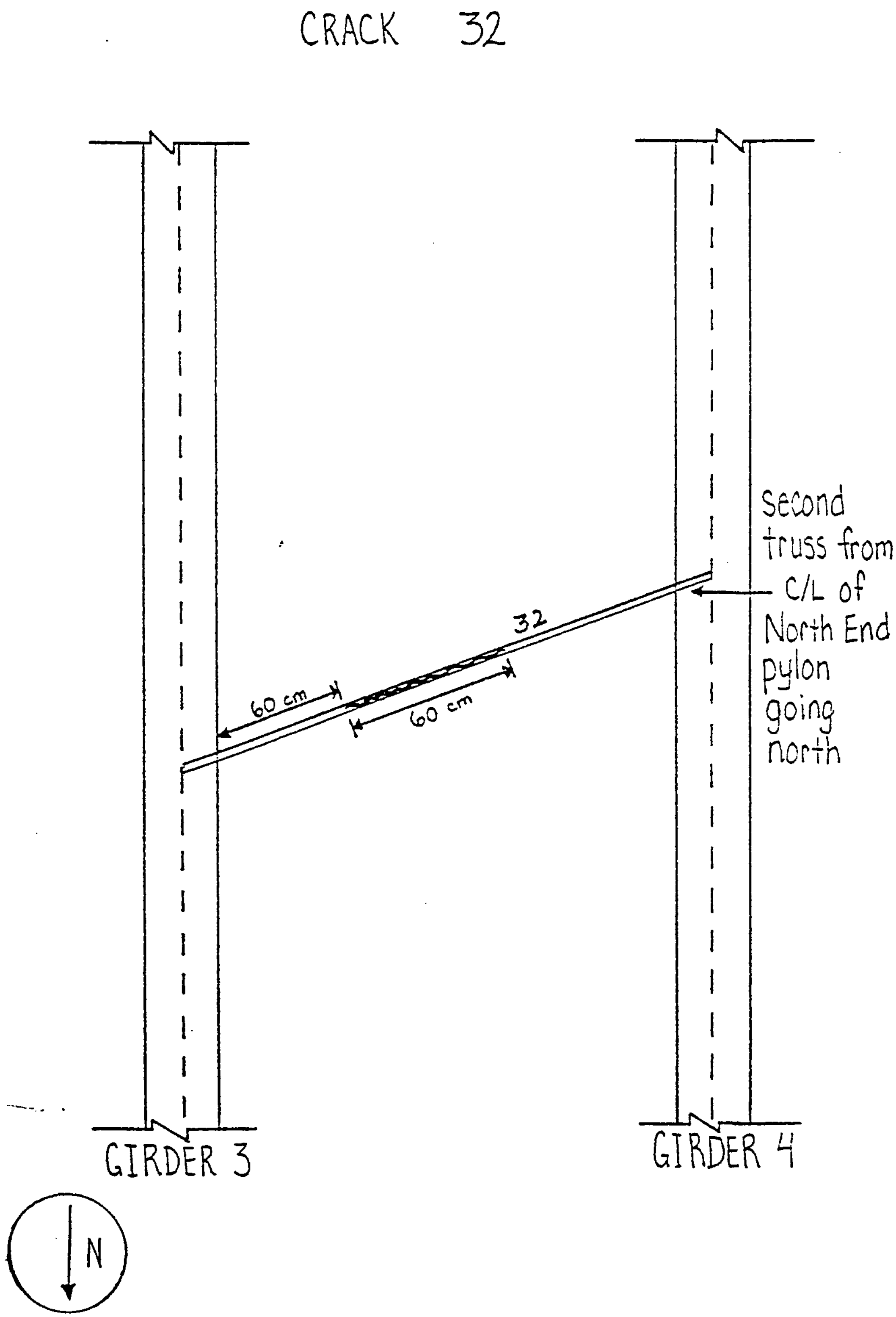
Sketch No. 10 Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)

CRACK 22



(Not to scale)

Sketch No. 1P Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)



(Not to scale)

Sketch No. 1Q Details Of Cracks In Bridge Deck Slab - Bottom Surface (Contd.)